



CARLO GAVAZZI SPACE SpA

ACOP

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Doc. N° ACP-RP-CGS-005 Issue: 2 Date: OCT 2005 Page 1 Of 127

Title : STRUCTURAL ANALYSIS AND DESIGN REPORT

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CHANGE RECORD			
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ACOP

STRUCTURAL ANALYSIS AND DESIGN REPORT

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1. SCOPE OF THE DOCUMENT

This report provides the structural analysis for ACOP to satisfy Space Shuttle and ISS safety criteria. It contains the description of Finite Element model developed to verify the safety of ACOP structure and the required natural frequency analysis, stress analysis and joint analysis of normal configuration and fail-safe configuration for ACOP Critical Design Review (CDR).

2. DOCUMENTS

2.1 APPLICABLE DOCUMENTS

AD	Doc. Number	Issue / Date	Rev.	Title / Applicability
1	SSP 52000-IDD-ERP	D / 08/03		EXpedite the PProcessing of Experiments to Space Station (EXPRESS) Rack Payloads Interface Definition Document
2	NSTS/ISS 13830	C / 01/12/1996		Implementation Procedures for Payloads System Safety Requirements – For Payloads Using the STS & ISS.
3	JSC 26493	17/02/1995		Guidelines for the preparation of payload flight safety data packages and hazard reports.
4	SSP 50004	April 1994		Ground Support Equipment Design requirements
5	SSP-52000-PDS	March 1999	B	Payload Data Set Blank Book
6	SSP 57066	October 28, 2003		Standard Payload Integration Agreement for EXPRESS/WORF Rack Payloads
7	GD-PL-CGS-001	3 / 17/03/99		PRODUCT ASSURANCE & RAMS PLAN
8	SSP 52000 PAH ERP	Nov. 1997		Payload Accommodation Handbook for EXPRESS Rack
9	SSP 50184	D / Feb. 1996		Physical Media, Physical Signaling & link-level Protocol Specification for ensuring Interoperability of High Rate Data Link Stations on the International Space Program
10	SSP 52050	D / 08/06/01		S/W Interface Control Document for ISPR ***ONLY FOR HRDL, SECTION 3.4 ***
11	ECSS-E-40	A / April 1999	13	Software Engineering Standard
12	AMS02-CAT-ICD-R04	29/08/2003	04	AMS02 Command and Telemetry Interface Control document. Section AMS-ACOP Interfaces
13	SSP 52000-PVP-ERP	Sept. 18, 2002	D	Generic Payload Verification Plan EXpedite the PProcessing of Experiments to Space Station (EXPRESS) Rack Payloads
14	NSTS 1700.7B	Rev. B Change Packet 8 / 22.08.00		Safety Policy and Requirements for Payloads using the STS
15	NSTS 1700.7B Addendum	Rev. B Change Packet 1 01.09.00		Safety Policy and Requirements for Payloads using the International Space Station
16	SSP 52005	Dec. 10, 1998		Payload Flight equipment requirements and guidelines for safety critical structures
17	NSTS 18798B	Change Packet 7 10.00		Interpretation of NSTS Payload Safety Requirements
18	MSFC-HDBK-527	15/11/86	E	Materials selection list for space hardware systems Materials selection list data
19	GD-PL-CGS-002	1/ 12-02-99		CADM Plan
20	GD-PL-CGS-004	2/07-04-03		SW Product Assurance Plan
21	GD-PL-CGS-005	2/09-05-03		SW CADM Plan

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2.2 REFERENCE DOCUMENTS

RD	Doc. Number	Issue / Date	Rev.	Title
1	GPQ-MAN-02	1		Commercial, Aviation and Military (CAM) Equipment Evaluation Guidelines for ISS Payloads Use
2	BSSC (96)2	1 / May 96		Guide to applying the ESA software engineering standards to small software projects
3	GPQ-MAN-01	2 / Dec. 98		Documentation Standard for ESA Microgravity Projects
4	MS-ESA-RQ-108	1 / 28-Sep-2000		Documentation Requirements For Small And Medium Sized MSM Projects
5	PSS-05			Software Engineering Standards
6	GPQ-010	1 / May 95	A	Product Assurance Requirements for ESA Microgravity Payload. Including CN 01.
7	GPQ-010-PSA-101	1		Safety and Material Requirements for ESA Microgravity Payloads
8	GPQ-010-PSA-102	1		Reliability and Maintainability for ESA Microgravity Facilities (ISSA). Including CN 01
9	SSP 52000-IDD-ERP	E / 09/09/03		EXPedite the PRocessing of Experiments to Space Station (EXPRESS) Rack Payloads Interface Definition Document
10	ACD-Requirements-Rev-BL	September 2005	Base Line	ACOP Common Design Requirements Document
11	MIL-HDBK-5	J/2003	H	Metallic Materials and Element for Aerospace Vehicle Structures
12	NSTS 08307	July, 1998	A	Criteria for Preloaded Bolts
13		June, 1973		E. F. BRUHN – Analysis & Design Of Flight Vehicle Structure

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3. COMPLIANCE MATRIX

In the following table the list of the requirement for the ACOP structure analysis is provided:

Requirement	Reference	Item	Notes
Minimum natural frequency compatibility	AD 1 Section 4.1.1.1	EXPRESS payload frequency compatibility	Equal to or exceeding 35 Hz
Minimum natural frequency compatibility	AD 1 Section 4.1.1.2	Middeck payload frequency compatibility	Equal to or exceeding 30 Hz
Positive margin of safety	AD 1 Section 4.1.2.1	EXPRESS rack low frequency launch and landing loads	Factor of safety for yielding =1.25 Factor of safety for ultimate =2.0
Positive margin of safety	AD 1 Section 4.1.2.2	Middeck low frequency launch and landing loads	Factor of safety for yielding =1.25 Factor of safety for ultimate =2.0
Positive margin of safety	AD 1 Section 4.2.1	Middeck emergency landing load	
Positive margin of safety	AD 1 Section 4.2.2	EXPRESS rack emergency landing load	May be neglected for analysis using low frequency loads
Positive margin of safety	AD 1 Section 4.3.1	EXPRESS rack random vibration loads	Combined into EXPRESS low frequency loads
Positive margin of safety	AD 1 Section 4.3.2	Middeck random vibration loads	Has been included into Middeck low frequency liftoff loads.
Limitation of mass-to-CG	AD 1 Section 4.4	Payload mass properties limits	Mass-to-CG relationship conformation
Positive margin of safety	AD 1 Section 4.5	On-orbit load	Consider crew-induced loads Neglect low frequency load
Positive margin of safety	RD 16 Section 4.3	Depressurization / Re-pressurization load	ACOP is an open structure and need not consider this load
Positive margin of safety	RD 16 Section 4.2.6	Thermal load	Use material derating factor to cover thermal effect
Positive margin of safety	AD 1 Section 4.9.1	Ground handling load	Level of Ground handling load is low and not considered, with the exception of the LC 51
Positive margin of safety	RD 16 Section 7.2.2	Test load	Four kinds of test load considered

Table 3-1: Compliance Matrix

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4. ACRONYMS AND ABBREVIATIONS

ACRONYMS	FULL TEXT
ACOP	AMS-02 Crew Operation Post
AVT	Acceptance Vibration Test
EXPRESS	EXpedite the PRocessing of Experiments Space Station
CG	Centre of Gravity
DoF	Degree of freedom
FE	Finite Element
FEM	Finite Element Model
FSu	Ultimate Factor of Safety
FSy	Yield Factor of Safety
HDD	Hard Disk Driver
LCD	Liquid Crystal Displayer
MDL	Mid Deck Locker
MoS	Margin of Safety
MoSu	Margin of Safety against ultimate failure
MoSy	Margin of Safety against material yielding
QAVT	Qualification for Acceptance Vibration Test
QVT	Qualification for Vibration Test
RVLF	Random Vibration Load Factor

Table 4-1: Acronyms

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5. HARDWARE DESCRIPTION

The ACOP System is a reliable special purpose computer intended to fly on the International Space Station (ISS) as a payload installed into an EXPRESS ISPR in the NASA US laboratory module. The main objective of ACOP is to provide an ISS Internal Facility capable of supporting the AMS-02 experiment by recording the Science data.

The ACOP system shall be installed in the U.S. Laboratory Module, on the ISS, in one EXPRESS rack

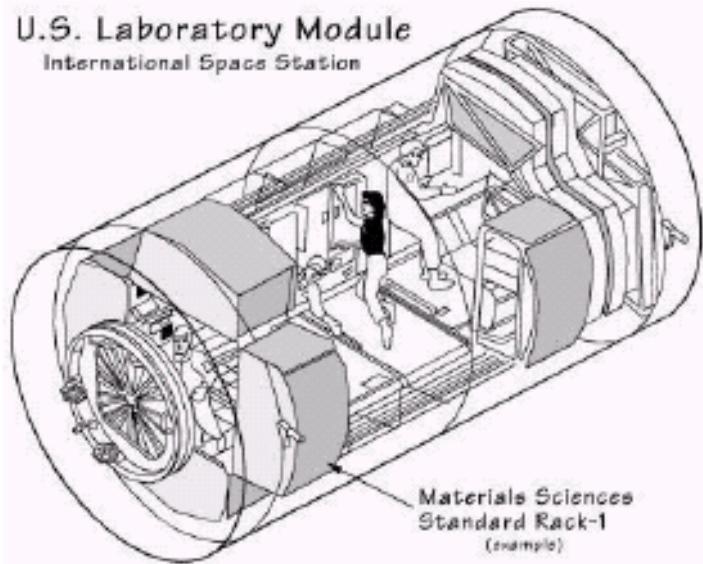


Figure 5-1 US Lab

The next figure shows ACOP installed in such a rack (the location within the rack is just an example, the actual location will be determined by the ISS program).

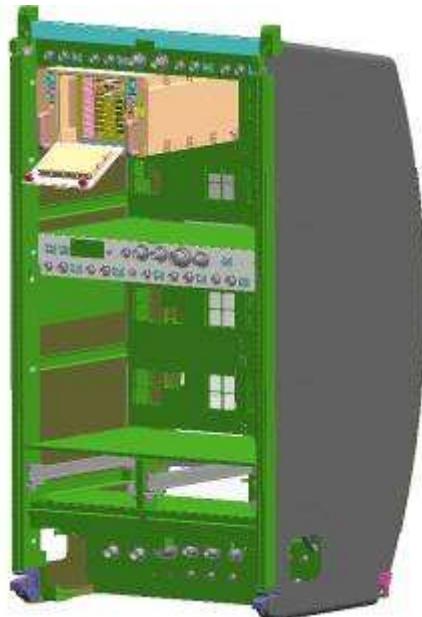


Figure 5-2 ACOP in the EXPRESS Rack (location for example)

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The ACOP dimension is 460x535x273mm meeting the Mid Deck Locker (MDL) form factor as modified for the EXPRESS Rack Payloads. The enclosure of ACOP (the Locker) is made of Aluminum alloy 7075 T7351 and the chassis inside is made of aluminum alloy 6061 T6. The chassis provides a 6U Compact PCI card cage for electronic boards, the four slots for hard disk driver (HDD) and a lot of fins in two sides as heat sinks. The LCD is mounted to the front door of the locker for system monitoring and control. The cooling air blows in and sucks out by two fans in the backplate; and there is a thin baffle between two fans to separate the cold and hot air flow. At corners of locker backplate, four captive bolts are used to fasten ACOP structure and EXPRESS rack backplate together.

In the following figures the 3D drawings of ACOP structure is presented:

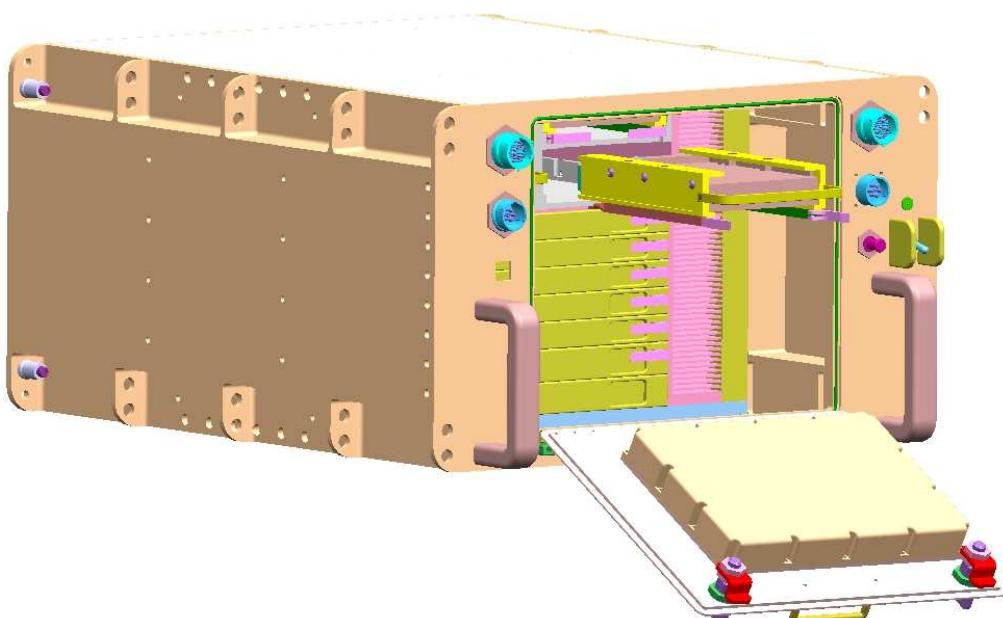


Figure 5-2: View of ACOP with the front door open



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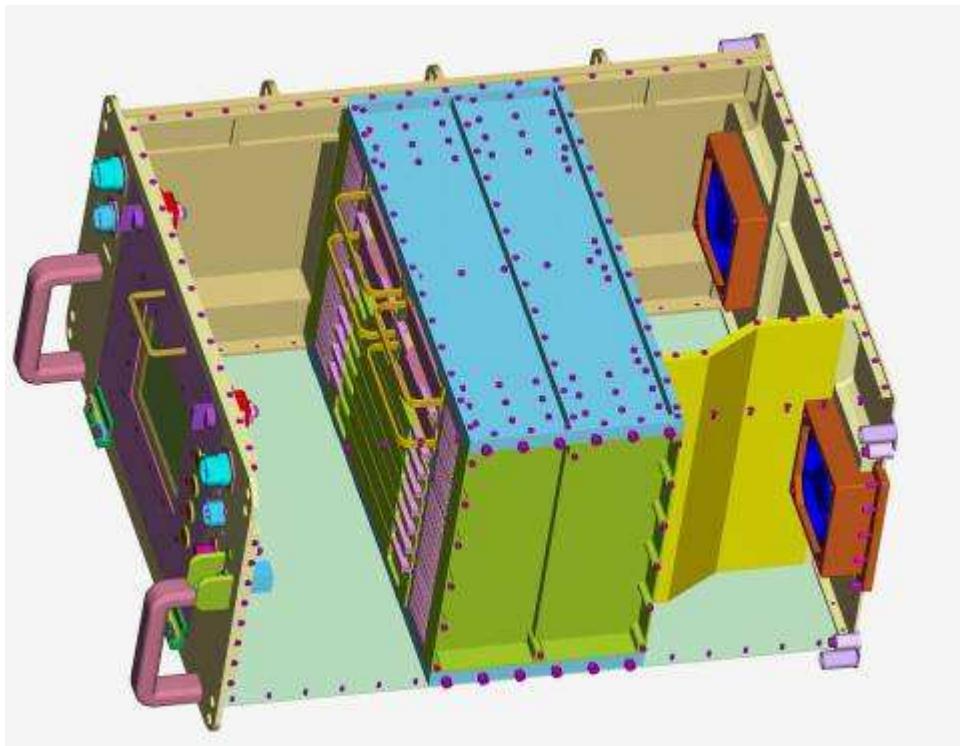


Figure 5-3: View of ACOP

structure (Top plate and right side plate removed)

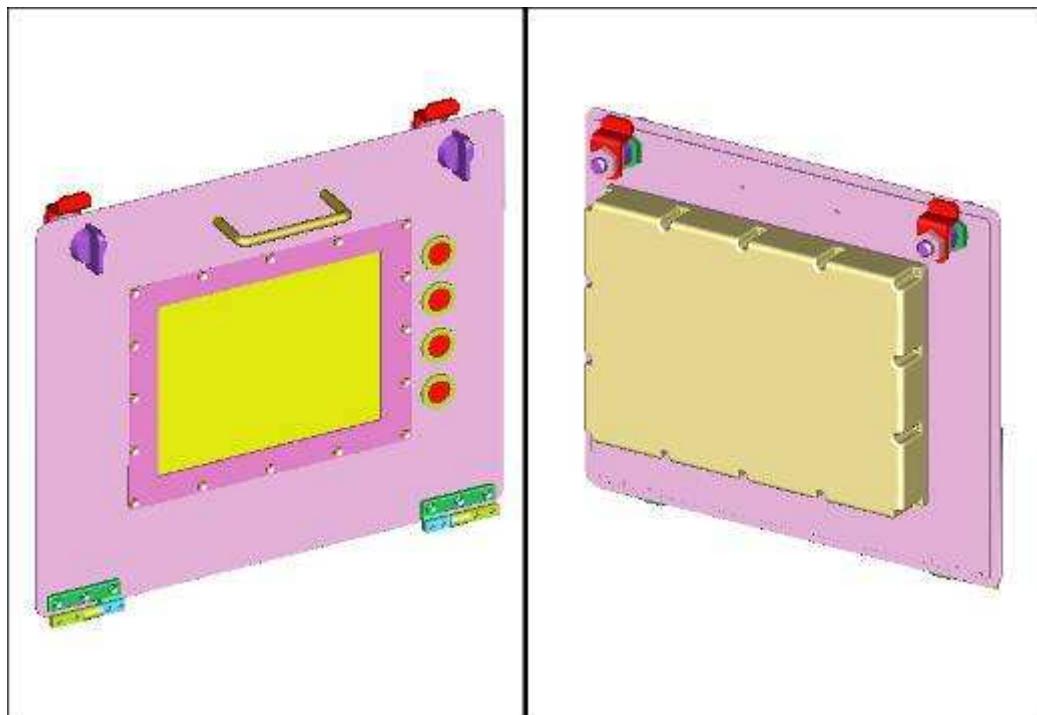


Figure 5-4: The view of Front door structure



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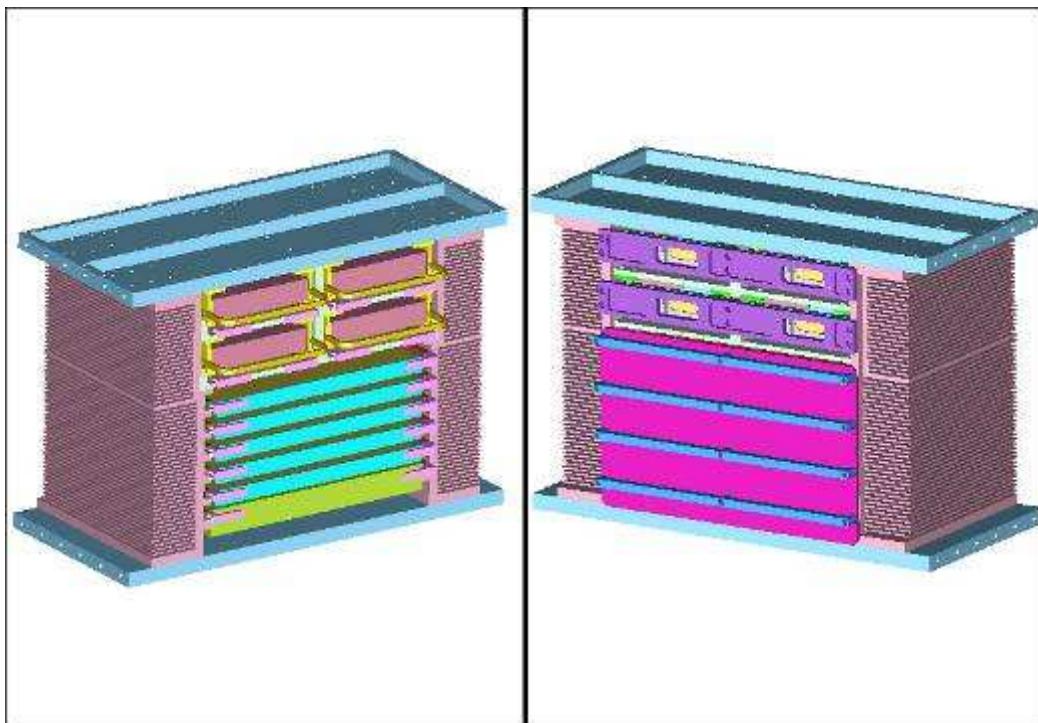


Figure 5-5: The view of chassis assembly with boards and HDD

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6. FEM DESCRIPTION

Basic on 3D mechanical design drawing and mass budge of ACOP engineering model, the finite element model was built to verify structural safety. Figures and explanations that describe the Finite Element model used for the analysis are list as follows.

6.1 USED SOFTWARE

MSC/NASTRAN v2004 software is used for analysis, including model check, natural modal analysis, and static stress analysis.

EDS/I-DEAS ver.10m2 software is used for Pre/Post processing, including FE model construction, results plotting.

6.2 MODEL UNITS

The SI unit is used in this report, and the content of unit system used lists as follows:

Length:	meter (m)
Mass:	kilogram (kg)
Force:	Newton (N)
Material densities:	kg/m ³
Young's module:	N/m ² (Pa)
Material strength :	N/m ² (Pa)
Stress:	N/m ² (Pa)



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6.3 MODEL COORDINATE SYSTEM

The local coordinate system of ACOP, defined in the following figure, is conform to AD1.

In order to be consistent with the load directions of EXPRESS rack, the coordinate system used in the FE model is defined as Figure 6-1. Three axis directions of FE model coordinate system are same as ISPR coordinate system used in EXPRESS rack payload.

In the following figure and table the differences among the ACOP, ACOP FE and ISPR coordinate system are presented:

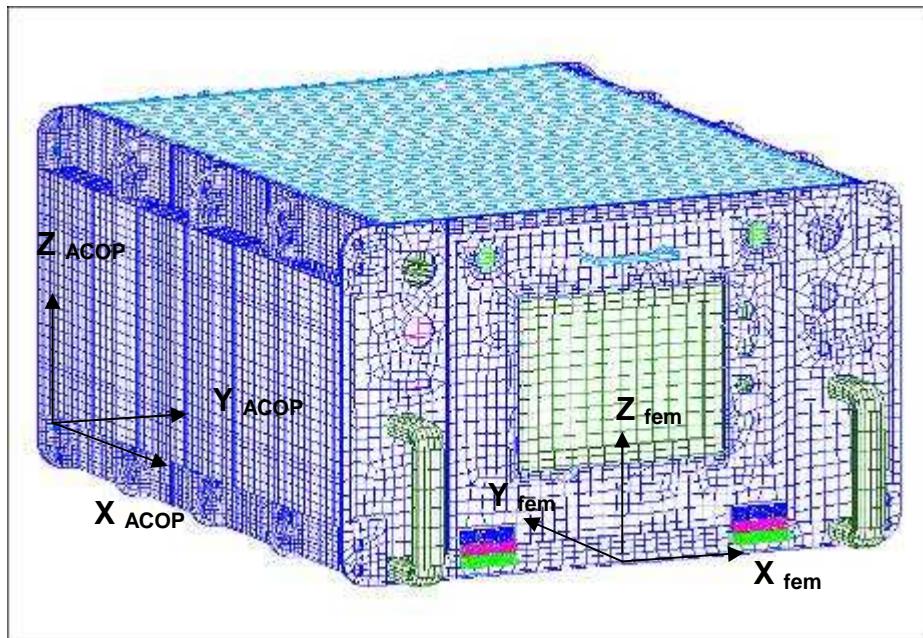


Figure 6-1: The coordinate systems of ACOP and ACOP FE model

COORDINATE SYSTEM CROSS REFERENCE TABLE					
Coord orientation			Coord origin (wrt ACOP Coord)		
ACOP Axis	FE model Axis	ISPR Axis	ACOP Axis	FE model Axis	ISPR Axis
X _{ACOP}	-Y _{fem}	-Y	0	+0.535m	NA
Y _{ACOP}	X _{fem}	X	0	+0.217m	NA
Z _{ACOP}	Z _{fem}	Z	0	-0.031m	NA

Table 6-1: coordinate system reference table

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The coordinate system of FE model is defined as:

Origin: locate at a central point in the bottom edge of locker front plane.

Orientation: Face to locker front plane, the X-axis points to right direction. The Z-axis is in the front plane of locker, perpendicular to the X-axis positive upward to the top plane of locker. The Y-axis completes a right-hand system.

The local coordinate system of ACOP is defined as:

Origin: locate at a central point of type B joint hole on the left bottom corner of locker rear plane.

Orientation: Face to locker front plane, the Y-axis points to right direction. The Z-axis is in the rear plane of locker, perpendicular to the Y-axis positive upward to the top plane of locker. The X-axis completes a right-hand system.

6.4 MODEL MATERIALS

The material aluminium alloy AL 7075-T7351 is used for the entire structure except chassis. Due to the better thermal conductivity and easy to manufacture AL6061-T6 is used for the chassis. The material FR4 is used for electronic boards. Mechanical properties of aluminium and FR4 are list in the following tables.

	AL 7075		AL 6061	
source	MIL-HDBK-5H		MIL-HDBK-5H	
Specification	AMS 4078 and QQ-A-250/12		AMS 4127and QQ-A-367	
Form	Plate		Hand forging	
Temper	T7351		T6	
Thickness	0.5~1.0 in		2.0~4.0 in	
basis	A		S	
	Ksi	MPa	ksi	MPa
Ftu	68	468.9	38	262
Fty	57	393	35	241.3
Fsu	38	262	25	172.4
Fbru(e/D=1.5)	103	710.2	61	420.6
Fbry (e/D=1.5)	81	558.5	54	372.4
E	10300	71020.	9900	68265.
	lb/in³	kg/m³	lb/in³	kg/m³
Density	0.101	2.79E+3	0.098	2.72E+3
Poisson Ratio	0.33		0.33	

Table 6-2: Mechanical and physical properties of AL 7075

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Material	FR4	
	ksi	MPa
Ftu	29	200
Fty	N/A	N/A
Fcu	50.7	349.7
Fcy	N/A	N/A
Fbru(e/D=1.5)	--	--
Fbry(e/D=1.5)	N/A	N/A
E	2.61E+3	1.80E+4
	lb/in³	kg/m³
Density	6.5E-02	1.799E+3
Poisson Ratio	0.3	
Reference	Vonroll Isola catalogue	01/06/1995

Table 6-3: Mechanical and physical properties of FR4

Base on engineering experience we estimate the reasonable density value of boards in FE model to cover the weight of electronic components and to conform to the FE mass budge in the section 6.7 . The densities of electronic boards used in FE model are shown in the following table.

Electronic board density (kg/m ³)	
ACOP-SBC	6690.
ACOP-T101	5860.
ACOP-T102	5860.
ACOP-T103	5860.
ACOP-T104	5860.
ACOP-BP	1910.
ACOP-PS	6490.

Table 6-4: Assumed density of electronic boards.

The LCD is simply simulated by a 0.4mm thickness stainless steel housing (assume AISI 304 used) and a 3.0mm thickness acrylic resin to provide a reasonable stiffness for structural analysis. The mass of LCD FE with modified densities conforms to the weight measured actually. The FR4 material is used for the LCD Video Interface board (ACOP-VI). A protection layer mounted in front of LCD is made of Lexan 953A. The mechanical properties of LCD module are shown as the following table.

Material	Properties				
	E (MPa)	Density (kg/m ³)	Poisson Ratio	Ftu (MPa)	Fty (MPa)
AISI 304 steel ^[1]	200000	8000.	0.27	503.4	179.
Acrylic resin ^[2]	1860	2334.	0.2	N/A	71
FR4 ^[3]	18000	2207.	0.3	200	N/A
Lexan 953A ^[4]	2350	1200.	0.2	N/A	63
Reference	^[1] MIL-HDBK-5H, AMS 5901, Annealed ^[2] ASM Thermoplastics DatabankQ2 1998 1.0 ^[3] Vonroll Isola catalogue ^[4] GE plastic products data sheet				

Table 6-5: Elastic modulus and density used in LCD module

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The Southco compression latches (E3-57) is selected to install in front door upper edge for clamping. The housing and shaft of latch are made of AISI 316 stainless steel, and the jam nuts and pawl are 304 stainless steel. Other important components are a pair of hinge made of AISI 316 stainless steel installed between front door and front panel by two adapters made of AM-355 stainless steel... The mechanical properties of related parts are shown as Hinge and Figure FIGURE 6-5

Material	Properties				
	E (MPa)	Density (kg/m ³)	Poisson Ratio	Ftu (MPa)	Fty (MPa)
Stainless steel					
316 steel ^[1]	186200	8000.	0.27	855.	475.8
304 steel ^[2]	200000	8000.	0.27	503.4	179.
AM-355 steel ^[3]	200000	7822.	0.32	1172.	1068.8
Reference	^[1] MIL-HDBK-5H, AMS 5907, ¼ Hard ^[2] MIL-HDBK-5H, AMS 5901, Annealed ^[3] MIL-HDBK-5H, AMS 5743, SCT1000				

Table 6-6: Elastic modulus and densities of Latch and Hinge

The material and strength of bolts will be defined in the chapter relevant to joint analysis.

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6.5 FEM MODEL COMPONENTS DESCRIPTION

The geometry of Finite Element (FE) model comes from CAD design model. The FE model totally uses 108860 grid points and 73979 elements to simulate the ACOP structure without hard disk drivers that are not in chassis during ascent. Every item simulated in the FE model is described as follows:

MODEL SUMMARY	
GRID POINTS	108860
CHEXA ELEMENTS	48918
CPENTA ELEMENTS	738
CTETRA ELEMENTS	8894
CQUAD4 ELEMENTS	13090
CTRIA3 ELEMENTS	112
CBAR ELEMENTS	1230
CONM2 ELEMENTS	4
RBAR ELEMENTS	468
RBE2 ELEMENTS	530
TOTAL ELEMENTS	73979

Table 6-7: FE MODEL SUMMARY

Next figures show the locker FE model. The summary description for locker FEM is list in Table 6-8

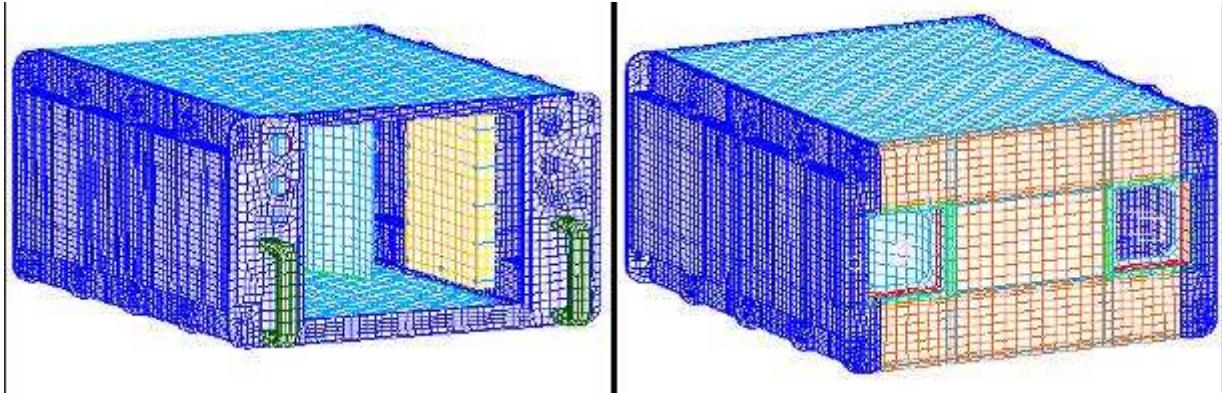


Figure 6-2: LOCKER FE MODEL



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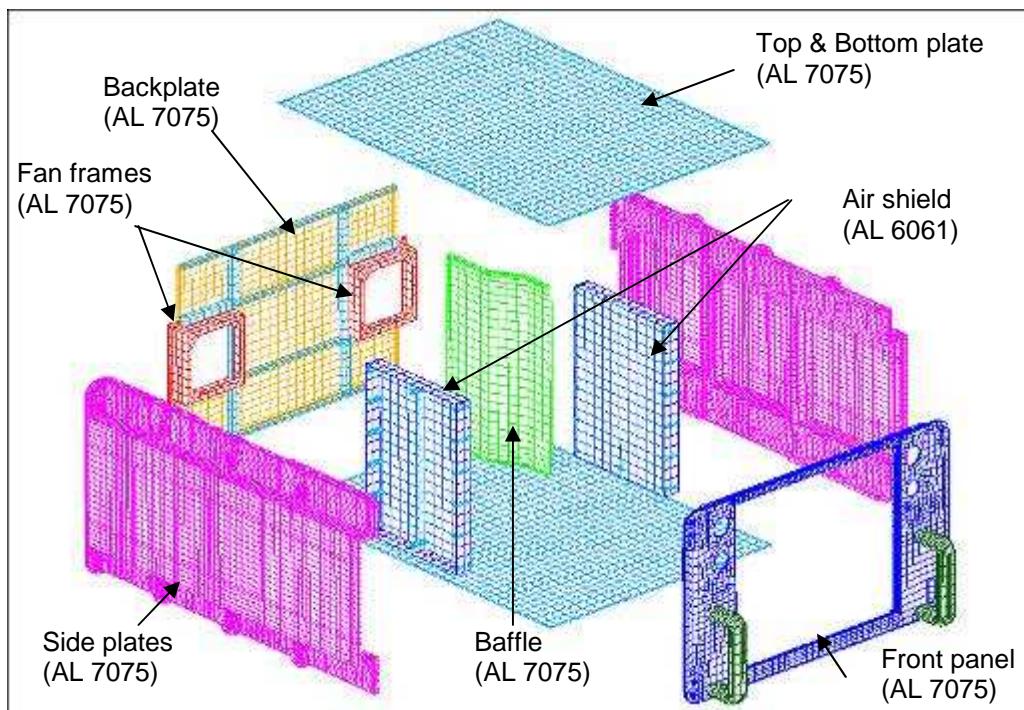


Figure 6-3: LOCKER FE MODEL (EXPLODING VIEW)

Locker FE Summary	
FEM Elements	CQUAD4 & CTRIA3 for top, bottom plate, backplate, baffle, air shield, fan frames CHEXA & CPENTA for front panel, side plates, handles CBAR for backplate stiffener, CONM2 for fans and air filters
Material	AL 7075-T7351 for others AL 6061-T6 for air shield
Connections	CBAR for all bolt joints RBAR & RBE2 for plate and stiffener

Table 6-8: LOCKER FEM CHARACTERISTICS



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Next figure shows the chassis assembly FE model. The summary description for chassis assembly FEM is list in Table 6-9.

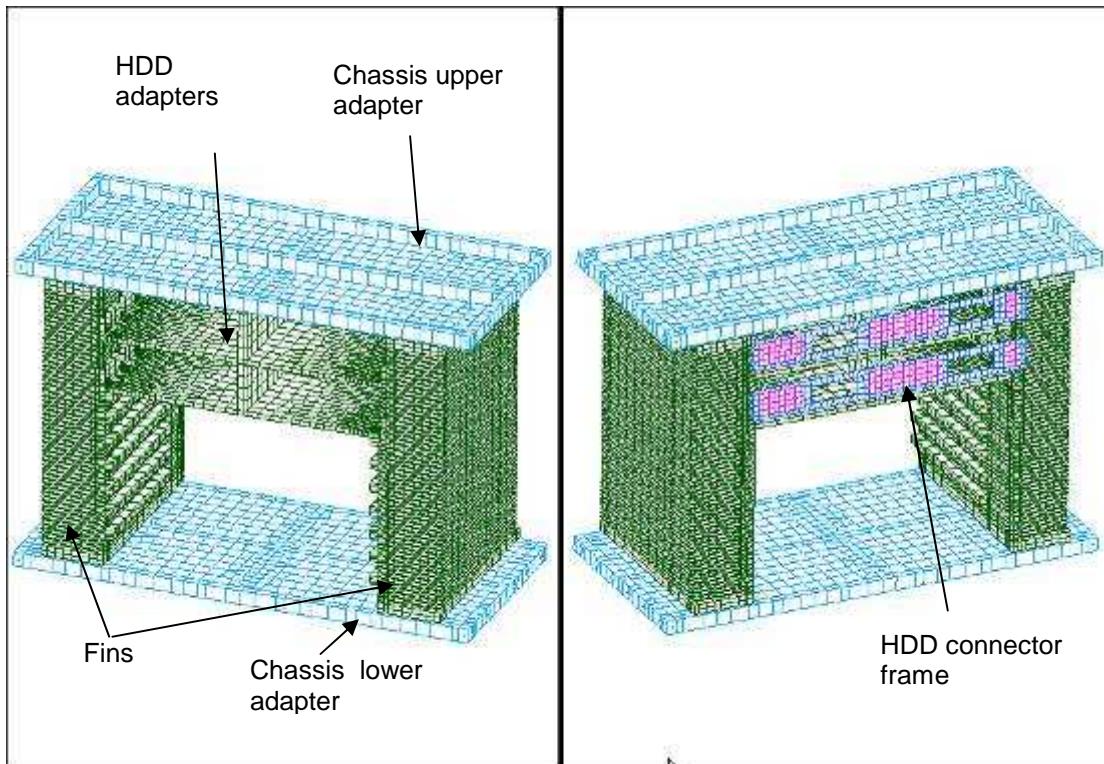


Figure 6-4: CHASSIS ASSEMBLY FE MODEL

Chassis FE Summary	
FEM Elements	CHEXA & CPENTA for fins, HDD frame CQUAD4 for upper, lower adapters and HDD connector frame CBAR for adapter stiffener
Material	AL 6061-T6 for all parts
Connections	CBAR for bolt joints RBAR & RBE2 for plate and stiffener

Table 6-9: CHASSIS FEM CHARACTERISTICS



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Next figures show the front door FE model. Some details of parts are shown in FIGURE 6-5 for hinge, FIGURE 6-6 for latch, Figure 6-7 and Figure 6-8 for LCD. The summary description for front door FEM is list in Table 6-10. The LCD is simply simulated by a 0.4mm thickness stainless steel housing (assume AISI 304 used) and a 3.0mm thickness acrylic resin to provide a reasonable stiffness for structural analysis. The FE mass of LCD conforms to the actual measured weight, and can provide reasonable structural dynamic characteristics.

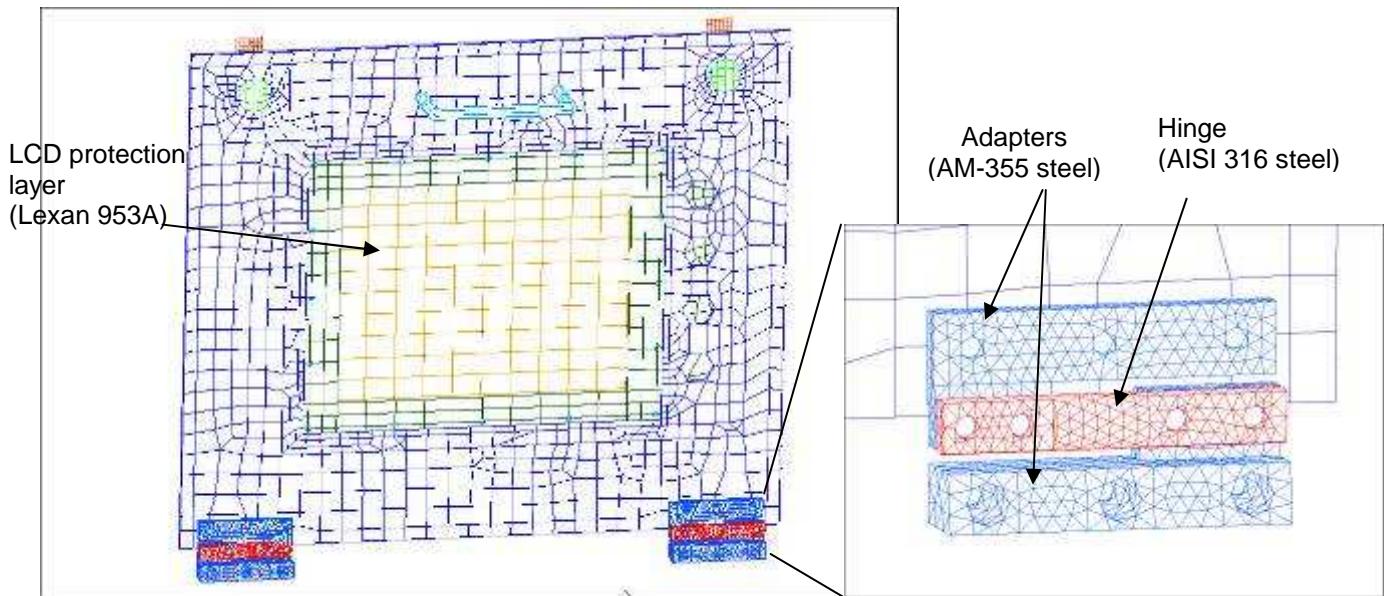


Figure 6-5: Front door FE model (front view, hinge)

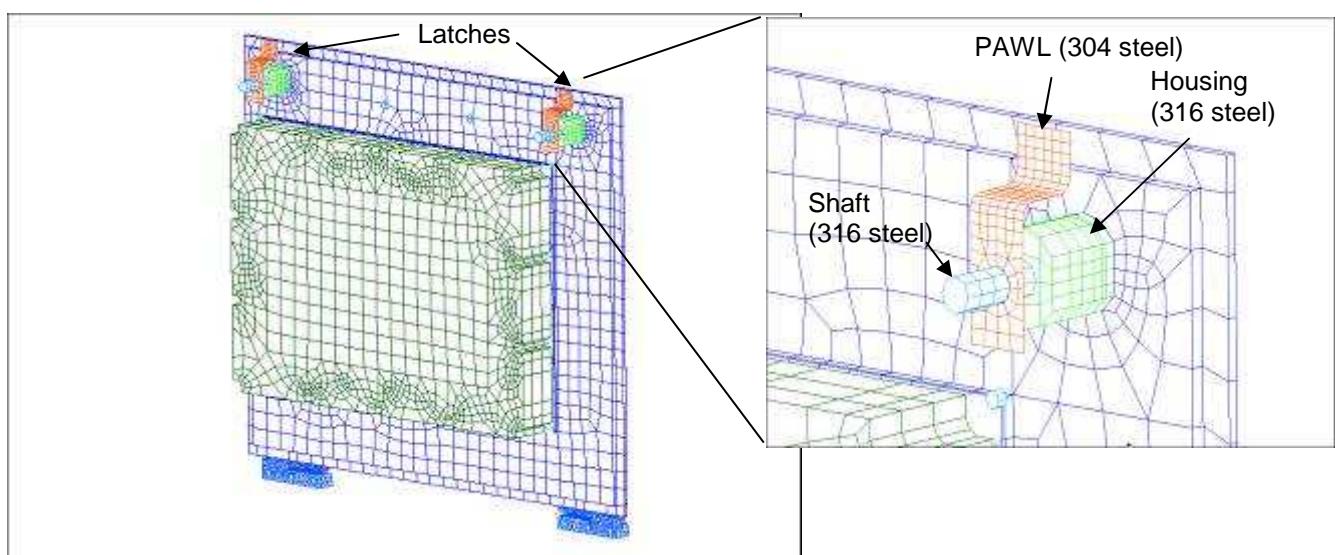


Figure 6-6: Front door FE model (back view, latch)



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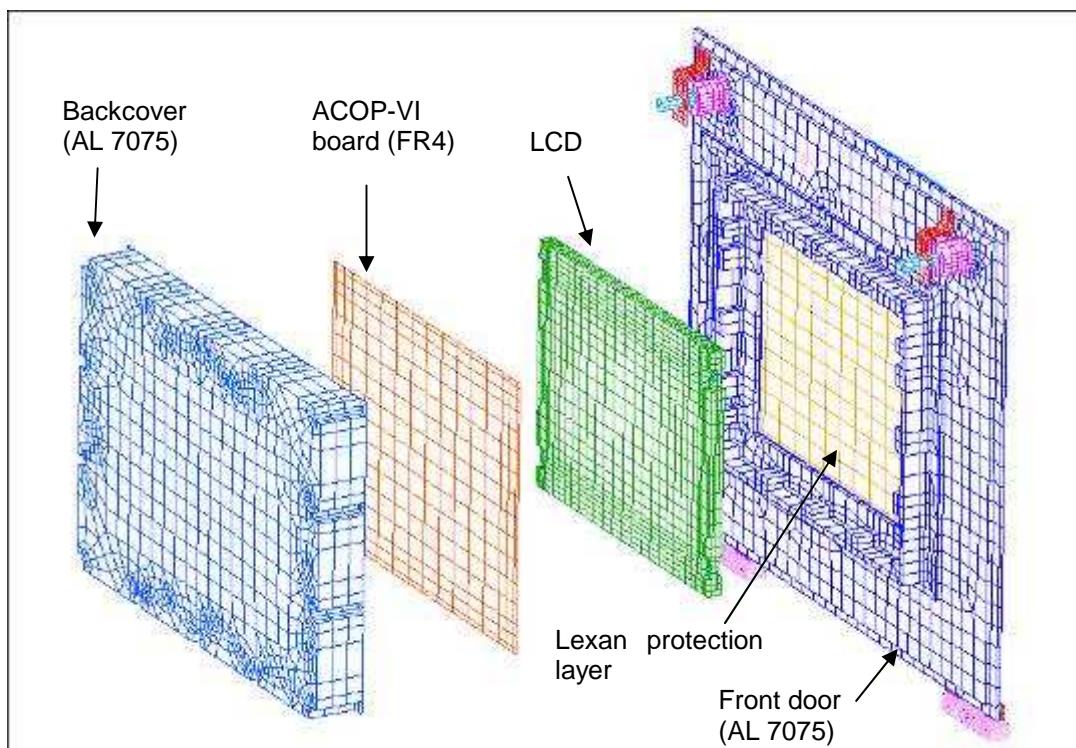


Figure 6-7: Front door FE model (backcover exploding diagram)

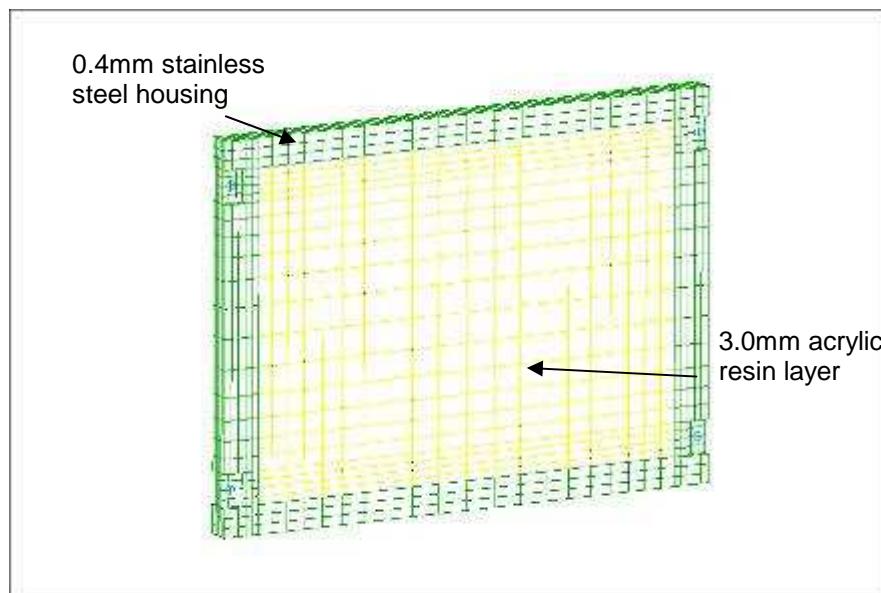


Figure 6-8: Front door FE Model (LCD front view)

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Front Door FE Summary	
FEM Elements	CQUAD4 & CTRIA3 for backcover, ACOP-VI board, LCD housing, LCD panel, Lexan protection layer PAWL of latch CHEXA & CPENTA for door, latch housing CTETRA for hinge and hinge adapters CBAR for latch shaft
Material	AL 7075-T7351 for door, backcover AISI 316 steel for latch shaft, latch housing AM-355 steel for hinge adapters AISI 316 steel for hinge FR4 for ACOP-VI board Lexan 953A for protection layer AISI 304 steel for PAWL, LCD housing Acrylic resin for LCD panel
Connections	CBAR for bolt joints

Table 6-10: Front door FEM characteristics



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Next figure shows electronic boards FE model. The summary description for electronic boards FEM is list in Table 6-11.

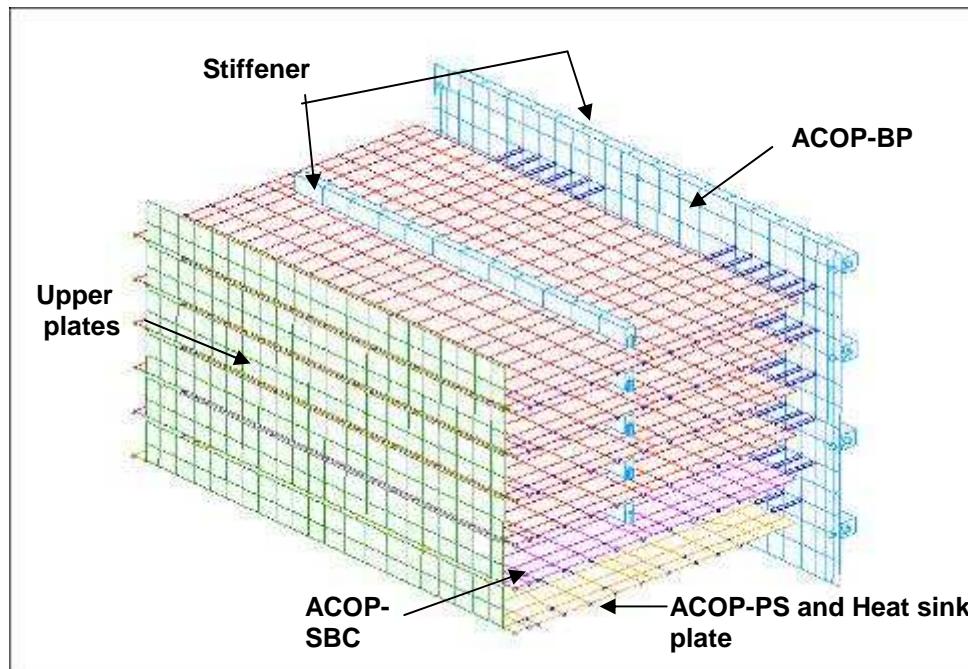


Figure 6-9: Electronic Boards FE Model

Electronic Boards FE Summary	
FEM Elements	CQUAD4 for boards, plates CBAR for stiffeners
Material	FR4 for all boards (including ACOP-SBC, ACOP-PS, ACOP-BP) AL6061 for stiffeners, heat sink plate, upper plates
Connections	CBAR for bolt joint RBE2 for board connectors

Table 6-11: Electronic boards FEM characteristics

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There are three types of FE model for different front door configurations.

1. When ACOP structure takes the negative Y direction ($-Y_{fem}$) initial loads on FE coordinate system, the front door will move outward and the pawl of latch will contact with front panel upper edges. Rigid connectors are used to simulate the contact behavior. This is the first type of FE model. This type of FE model is most similar to the launch configuration and also used for model check and modal analysis for load dimension.
2. When the positive Y direction ($+Y_{fem}$) initial load is applied to ACOP structure or the crew pushes the front door, the front door will contact with the front panel on the surrounding edges, and the pawl will have no reaction force occurred. The multi-point constrains of Y_{fem} are defined around the door and related front panel edges to simulate the contact behavior. This is the second type of FE model.
3. In current design the maximum open door angle can reach to 170 degree, the upper and the lower adapter of hinge will contact together to stop the door opening. We also consider the unintentional pressure induced by the crew on the back-cover of LCD module in ACOP structural analysis. The multi-point constrains are defined on the contact area between the upper and lower adapter of hinge to simulate the contact behavior. This is the third type of FE model.

The following figures show these three types of FE model details.

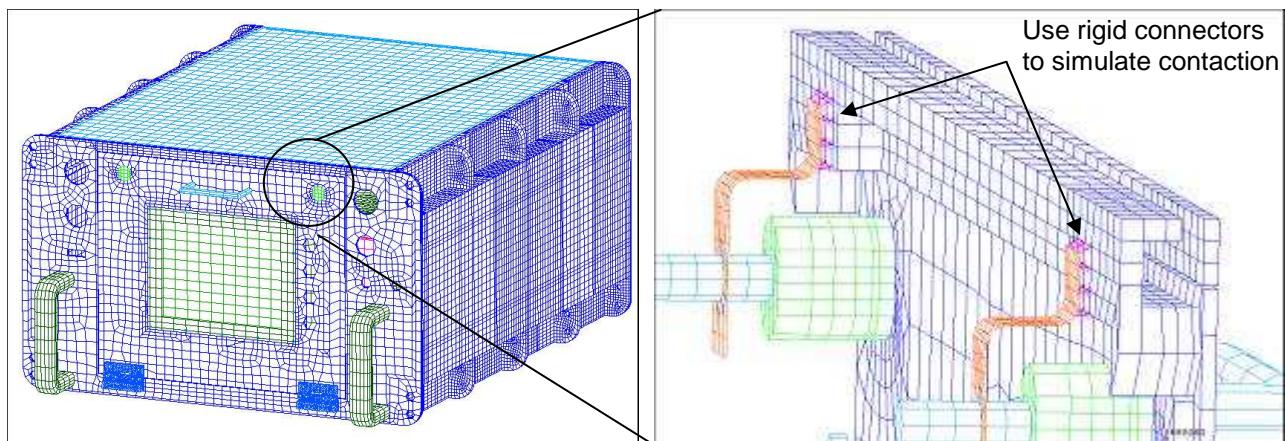


Figure 6-10: The first type FE model (for $-Y_{fem}$ direction initial load case)

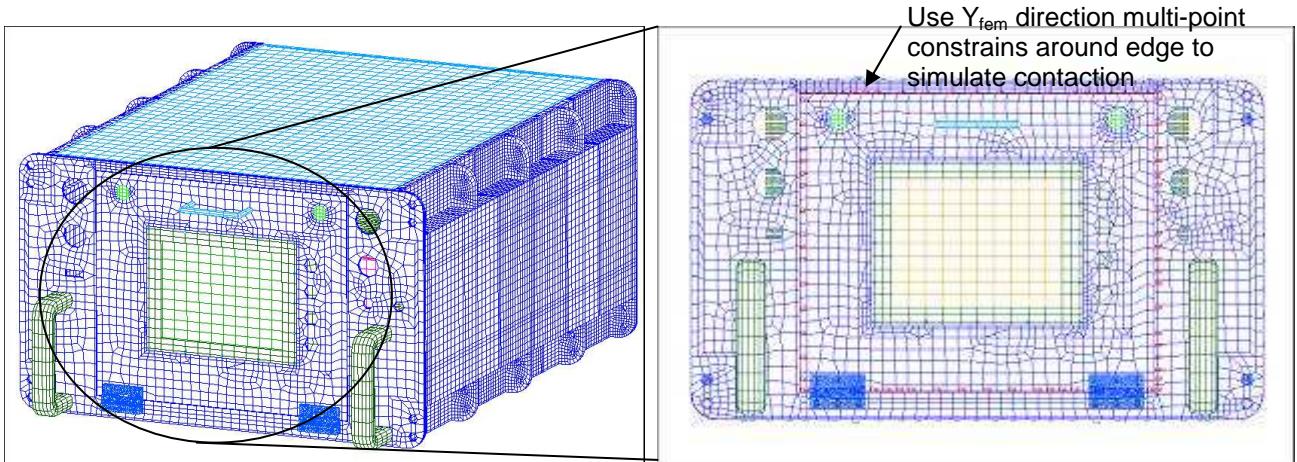


Figure 6-11: The second type FE model (for $+Y_{fem}$ direction initial load case and crew push load case)

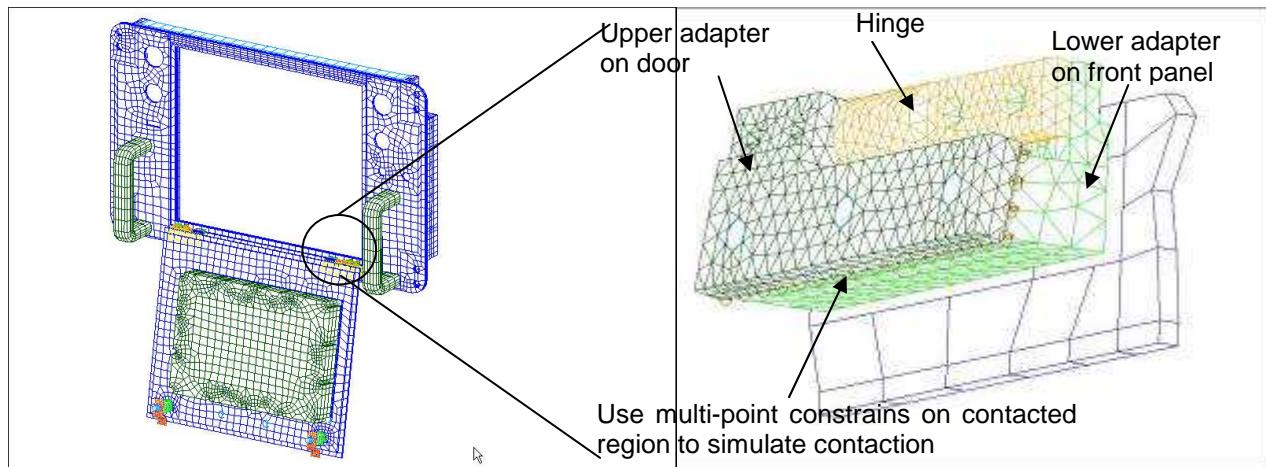


Figure 6-12: The third type FE model (for crew push load on the LCD back-cover in open door configuration)

The following Table shows the summary use of three types of FE model.

Type of FE model	Analysis items
First type (Latch contact)	Model Check, Modal analysis for load dimension, Static analysis (load cases of $-Y_{fem}$ initial load, crew pull or push at large handle, crew pull out or down on small handle)
Second type (Edge contact)	Static analysis (load cases of $+Y_{fem}$ initial load, crew induced pressure load on closed door, crew push or pull up, right, left on small handle)
Third type (Hinge contact)	Static analysis (Crew induced pressure load on opened door)

Table 6-12: The summary use of FE Models



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6.6 MODEL BOUNDARY CONDITIONS

ACOP crate is connected to the EXPRESS rack by four 1/ 4 inch captive sleeve bolts through the configuration B holes. All DoFs of fastened point at 4 corners of locker backplate are fixed shown in the following figures. The clamped point connects to all nodes in the edge of the hole by rigid bars.

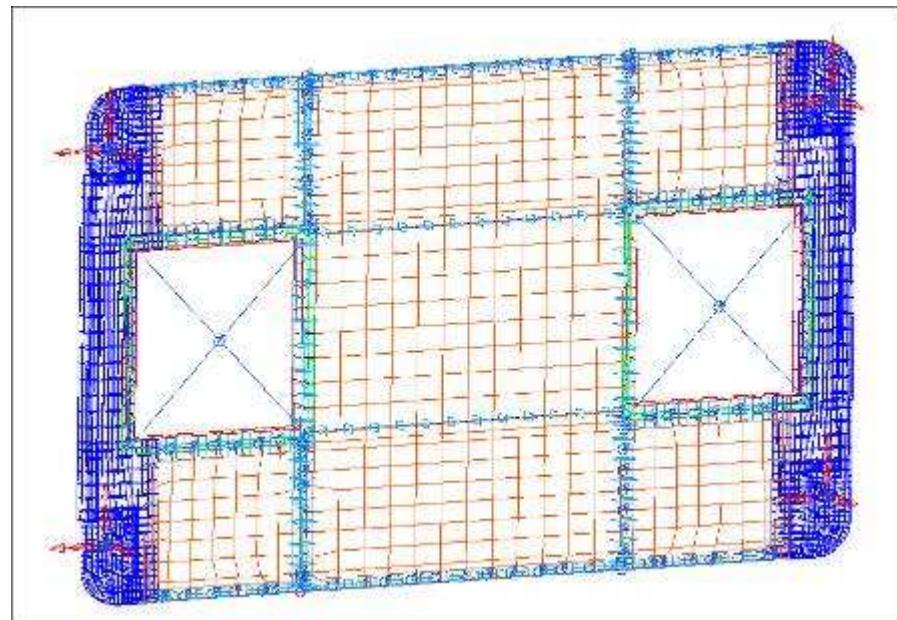


Figure 6-13: Boundary condition simulation



Figure 6-14: Local details for boundary condition

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6.7 MODEL MASS BUDGET

The model mass budge is abstracted from the power and mass budge of ACOP design model. It is shown as the following Table. HDD, HDD caddy, cables, connectors, buttons and captive sleeve bolts are not modelled in FE model. The 10% contingency mass of each part is added into the FE model for considering assembly or manufacture tolerance.

LOC	PART NUMBER	TYPE	DESCRIPTION	ACOP FM WEIGHT (g)	LAUNCH WEIGHT (g)	ORIGINAL FEM MASS (g)	ADD 10% CONTINGENCY FE MASS (g)
SLOT1	ACOP-SBC	Elec.	Single Board Computer	400.0	400.0	399.7	439.7
SLOT2	ACOP-T101	Elec.	Compact PCI 6U USB and Video	350.0	350.0	350.1	385.1
SLOT3	ACOP-T102	Elec.	Compact PCI 6U HRDL	350.0	350.0	350.1	385.1
SLOT4	ACOP-T103	Elec.	Compact PCI 6U SATA and Ethernet	350.0	350.0	350.1	385.1
SLOT5	ACOP-T104	Elec.	Spare	350.0	350.0	350.1	385.1
Power	ACOP-PS	Elec.	Power Distribution	1000.0	1000.0	1031.0	1134.1
Backplane	ACOP-BP	Elec.	Compact PCI Backplane	220.0	220.0	219.7	241.7
Left side	FAN-1	Elec.	Fan	170.0	170.0	190.0	209.0
Right side	FAN-2	Elec.	Fan	170.0	170.0	190.0	209.0
	ACOP-LCD	Elec.	LCD Monitor	187.0	187.0	187.8	206.6
	ACOP-VI	Elec.	Video Interface	100.0	100.0	100.0	110.0
HDD LOC 1	TBD	Elec.	Hot Plug SATA 250G HDD	582.0	0.0	0.0	0.0
HDD LOC 2	TBD	Elec.		582.0	0.0	0.0	0.0
HDD LOC 3	TBD	Elec.		582.0	0.0	0.0	0.0
HDD LOC 4	TBD	Elec.		582.0	0.0	0.0	0.0
	HDD-CADDY	Mech.	Hard Drive caddy x 4	1000.0	0.0	0.0	0.0
		Mech.	Connectors, Cable	2000.0	500.0	0.0	0.0
	ACOP-CHASSIS	Mech.	Compact PCI and hard drive chassis assembly	9096.0	9096.0	8842.0	9726.2
	ACOP-LOCKER	Mech.	Crate Body as ISS Locker assembly	12716.0	12716.0	12310.3	13541.3
TOTAL				30787.0	25959.0	24870.9	27358.0

Table 6-13: The mass budge of FE model

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6.8 MODEL CHECK

This section contains the summary tables to describe mathematical correctness of the FE model.

6.8.1 MODEL SIZE AND MASS PROPERTIES

There are 108860 grid points and 73979 elements in FE model, and mass equals to 27.358 kg with the centre of gravity (0.001, 0.264, 0.131) m based on the local coordinate of FE model.

MATHEMATICAL MODEL VERIFICATION RESULTS MODEL SIZE AND MASS PROPERTIES																																																																																																																																			
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	<table> <thead> <tr> <th style="text-align: center;">M O D E L S U M M A R Y</th></tr> </thead> <tbody> <tr> <td>NUMBER OF GRID POINTS = 108860</td></tr> <tr> <td>NUMBER OF CBAR ELEMENTS = 1230</td></tr> <tr> <td>NUMBER OF CHEXA ELEMENTS = 48918</td></tr> <tr> <td>NUMBER OF CONM2 ELEMENTS = 4</td></tr> <tr> <td>NUMBER OF CPENTA ELEMENTS = 738</td></tr> <tr> <td>NUMBER OF CQUAD4 ELEMENTS = 13090</td></tr> <tr> <td>NUMBER OF CTETRA ELEMENTS = 8894</td></tr> <tr> <td>NUMBER OF CTRIA3 ELEMENTS = 112</td></tr> <tr> <td>NUMBER OF RBAR ELEMENTS = 463</td></tr> <tr> <td>NUMBER OF RBE2 ELEMENTS = 530</td></tr> </tbody> </table>	M O D E L S U M M A R Y	NUMBER OF GRID POINTS = 108860	NUMBER OF CBAR ELEMENTS = 1230	NUMBER OF CHEXA ELEMENTS = 48918	NUMBER OF CONM2 ELEMENTS = 4	NUMBER OF CPENTA ELEMENTS = 738	NUMBER OF CQUAD4 ELEMENTS = 13090	NUMBER OF CTETRA ELEMENTS = 8894	NUMBER OF CTRIA3 ELEMENTS = 112	NUMBER OF RBAR ELEMENTS = 463	NUMBER OF RBE2 ELEMENTS = 530																																																																																																																							
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MASS AXIS SYSTEM (S)	MASS	X-C.G.	Y-C.G.	Z-C.G.																																																																																																																															
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Table 6-14: FEM model size and mass-Cog properties

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6.8.2 FREE-FREE AND HARDMOUNTED MODES

Only six rigid body modes exist in the result of the free-free boundary condition case, and no rigid body modes in the result of the harmdounted boundary condition case. The FEM passes the free-free and harmdounted modes checks.

MATHEMATICAL MODEL VERIFICATION RESULTS MASS PROPERTIES, FREE-FREE MODES AND HARDMOUNTED MODES							
RUN FILE NAMES							
free.dat, harmdounted.dat							
PARAMETERS :							
PARAM AUTOSPC YES, PARAM K6ROT 1.0							
RIGID BODY MODES CHECK	MODE	EXTRACTION	EIGENVALUE	RADIANS	REAL EIGENVALUES CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
	NO.	ORDER					
	1	1	-4.990790E-06	2.234008E-03	3.555533E-04	1.000000E+00	-4.990790E-06
	2	2	1.500814E-06	1.225077E-03	1.949771E-04	1.000000E+00	1.500814E-06
	3	3	4.669323E-06	2.160862E-03	3.439118E-04	1.000000E+00	4.669323E-06
	4	4	9.671655E-06	3.109928E-03	4.949605E-04	1.000000E+00	9.671655E-06
	5	5	2.349742E-05	4.847414E-03	7.714899E-04	1.000000E+00	2.349742E-05
	6	6	3.925740E-05	6.265573E-03	9.971969E-04	1.000000E+00	3.925740E-05
	7	7	9.974120E+05	9.987051E+02	1.589489E+02	1.000000E+00	9.974120E+05
HARDMOUNTED MODES CHECK	MODE	EXTRACTION	EIGENVALUE	RADIANS	REAL EIGENVALUES CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
	NO.	ORDER					
	1	1	6.566351E+05	8.103303E+02	1.289681E+02	1.000000E+00	6.566351E+05
	2	2	9.751000E+05	9.874715E+02	1.571610E+02	1.000000E+00	9.751000E+05
	3	3	1.119219E+06	1.057931E+03	1.683750E+02	1.000000E+00	1.119219E+06
	4	4	1.188849E+06	1.090343E+03	1.735335E+02	1.000000E+00	1.188849E+06
	5	5	1.353424E+06	1.163367E+03	1.851557E+02	1.000000E+00	1.353424E+06
	6	6	1.482976E+06	1.217775E+03	1.938149E+02	1.000000E+00	1.482976E+06
	7	7	1.498098E+06	1.223968E+03	1.948006E+02	1.000000E+00	1.498098E+06
	8	8	1.502994E+06	1.225966E+03	1.951186E+02	1.000000E+00	1.502994E+06

Table 6-15: FEM free-free modes and harmdounted modes

 CARLO GAVAZZI CARLO GAVAZZI SPACE SpA	ACOP STRUCTURAL ANALYSIS AND DESIGN REPORT	Doc N°: ACP-RP-CGS-005
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6.8.3 1 G CHECK

The resultant force for one unity of gravity load equals to the weight of structure in each axis. The FEM passes the 1 G check as the following table shown.

MATHEMATICAL MODEL VERIFICATION RESULTS 1 G CHECK								
RUN FILE NAME 1Gcheck.dat								
PARAMETERS: PARAM AUTOSPC YES, PARAM K6ROT 1.0								
		OLOAD RESULTANT						
		DAREA ID	LOAD TYPE	T1	T2	T3	R1 R2 R3	
		1	FX 2.683817E+02	---	---	---	3.527991E+01 -7.080290E+01	
			FY ---- 0.000000E+00	---	---	0.000000E+00	0.000000E+00	
			FZ ---- 0.000000E+00	---	0.000000E+00	0.000000E+00	0.000000E+00	
			MX ---- 0.000000E+00	---	---	---	---	
			MY ---- 0.000000E+00	---	---	---	---	
			MZ ---- 0.000000E+00	---	---	---	0.000000E+00	
			TOTALS 2.683817E+02	0.000000E+00	0.000000E+00	0.000000E+00	3.527991E+01 -7.080290E+01	
		2	FX 0.000000E+00	---	---	---	0.000000E+00 0.000000E+00	
			FY ---- 2.683817E+02	---	-3.527991E+01	---	3.456706E-01	
			FZ ---- 0.000000E+00	---	0.000000E+00	0.000000E+00	0.000000E+00	
			MX ---- 0.000000E+00	---	---	---	---	
			MY ---- 0.000000E+00	---	---	---	---	
			MZ ---- 0.000000E+00	---	---	---	0.000000E+00	
			TOTALS 0.000000E+00	2.683817E+02	0.000000E+00	-3.527991E+01	0.000000E+00 3.456706E-01	
		3	FX 0.000000E+00	---	---	---	0.000000E+00 0.000000E+00	
			FY ---- 0.000000E+00	---	0.000000E+00	---	0.000000E+00	
			FZ ---- 2.683817E+02	7.080290E+01	-3.456706E-01	---	---	
			MX ---- 0.000000E+00	---	---	---	---	
			MY ---- 0.000000E+00	---	---	---	---	
			MZ ---- 0.000000E+00	---	---	---	0.000000E+00	
			TOTALS 0.000000E+00	0.000000E+00	2.683817E+02	7.080290E+01	-3.456706E-01 0.000000E+00	
UNITY GRAVITY LOADING CHECK								
M=27.358(kg) G=9.81 (m/s ²) F=2.68382E+2 (N)								
SPCFORCE RESULTANT								
SUBCASE/ LOAD								
		DAREA ID	LOAD TYPE	T1	T2	T3	R1 R2 R3	
		1	FX -2.683817E+02	---	---	---	-3.730333E+01 1.427388E+02	
			FY ---- -4.931167E-11	---	3.805734E-03	---	-7.227133E+01	
			FZ ---- -5.707133E-10	---	-3.035341E-10	1.822447E+00	---	
			MX ---- 0.000000E+00	---	---	---	---	
			MY ---- 0.000000E+00	---	---	2.009727E-01	---	
			MZ ---- 0.000000E+00	---	---	---	3.354121E-01	
			TOTALS -2.683817E+02	-4.931167E-11	-5.707133E-10	-3.035341E-10	-3.527991E+01 7.080289E+01	
		2	FX 9.433698E-11	---	---	---	2.531936E-02 -5.017320E-11	
			FY ---- -2.683817E+02	---	3.524571E+01	---	-3.176216E-01	
			FZ ---- -7.698908E-11	---	-4.094680E-11	-2.576295E-02	---	
			MX ---- 0.000000E+00	---	---	3.419975E-02	---	
			MY ---- 0.000000E+00	---	---	4.435866E-04	---	
			MZ ---- 0.000000E+00	---	---	---	-2.804905E-02	
			TOTALS 9.433698E-11	-2.683817E+02	-7.698908E-11	3.527991E+01	-4.656613E-10 -3.456706E-01	
		3	FX -1.429157E-09	---	---	---	-2.715686E-01 7.600973E-10	
			FY ---- -7.986500E-11	---	7.375306E+01	---	4.135459E-04	
			FZ ---- -2.683817E+02	---	-1.427388E+02	5.849691E-01	---	
			MX ---- 0.000000E+00	---	-1.817136E+00	---	---	
			MY ---- 0.000000E+00	---	---	3.227011E-02	---	
			MZ ---- 0.000000E+00	---	---	---	-4.135463E-04	
			TOTALS -1.429157E-09	-7.986500E-11	-2.683817E+02	-7.080289E+01	3.456706E-01 3.817475E-10	
EPSILON		LOAD SEQ. NO.	EPSILON	EXTERNAL WORK				
		1	3.6982036E-12	9.6255227E-04				
		2	1.8065768E-12	2.5165520E-04				
		3	3.7099798E-12	1.5625452E-03				

Table 6-16: FEM 1G check

 CARLO GAVAZZI CARLO GAVAZZI SPACE SpA	ACOP STRUCTURAL ANALYSIS AND DESIGN REPORT	<i>Doc N°:</i> ACP-RP-CGS-005 <i>Issue:</i> 2 <i>Date:</i> OCT 2005 <i>Page</i> 37 <i>of</i> 127
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6.8.4 STRAIN ENERGY CHECK

The FEM passes the strain energy check as the following table shown.

MATHEMATICAL MODEL VERIFICATION RESULTS STRAIN ENERGY CHECK			
RUN FILE NAME: Groundcheck.dat			
COMMAND: GROUNDCHECK(SET=ALL) =YES, PARAM AUTOSPC YES, PARAM K6ROT 1.0			
RESULTS OF RIGID BODY CHECKS OF MATRIX KGG (G-SET) FOLLOW: PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF 1.045610E+00			
	DIRECTION	STRAIN ENERGY	PASS/FAIL
	-----	-----	-----
STRAIN ENERGY CHECK	1	2.848223E-04	PASS
	2	3.195653E-05	PASS
	3	6.302087E-04	PASS
	4	4.778984E-05	PASS
	5	5.508809E-06	PASS
	6	2.352357E-05	PASS
RESULTS OF RIGID BODY CHECKS OF MATRIX KNN (N-SET) FOLLOW: PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF 1.309961E+00			
	DIRECTION	STRAIN ENERGY	PASS/FAIL
	-----	-----	-----
1	2.840373E-04	PASS	
2	4.923433E-05	PASS	
3	6.428979E-04	PASS	
4	4.759730E-05	PASS	
5	5.797581E-06	PASS	
6	2.377150E-05	PASS	
RESULTS OF RIGID BODY CHECKS OF MATRIX KNN+AUTO (N+AUTOSPC-SET) FOLLOW: PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF 1.309961E+00			
	DIRECTION	STRAIN ENERGY	PASS/FAIL
	-----	-----	-----
1	2.840373E-04	PASS	
2	4.923433E-05	PASS	
3	6.428979E-04	PASS	
4	4.759730E-05	PASS	
5	5.797581E-06	PASS	
6	2.377150E-05	PASS	
RESULTS OF RIGID BODY CHECKS OF MATRIX KFF (F-SET) FOLLOW: PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF 1.309961E+00			
	DIRECTION	STRAIN ENERGY	PASS/FAIL
	-----	-----	-----
1	2.840373E-04	PASS	
2	4.923433E-05	PASS	
3	6.428979E-04	PASS	
4	4.759730E-05	PASS	
5	5.797581E-06	PASS	
6	2.377150E-05	PASS	
RESULTS OF RIGID BODY CHECKS OF MATRIX KAA1 (A-SET) FOLLOW: PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF 1.309961E+00			
	DIRECTION	STRAIN ENERGY	PASS/FAIL
	-----	-----	-----
1	2.840373E-04	PASS	
2	4.923433E-05	PASS	
3	6.428979E-04	PASS	
4	4.759730E-05	PASS	
5	5.797581E-06	PASS	
6	2.377150E-05	PASS	

Table 6-17: FEM strain energy check

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6.9 MASS-TO-COG RELATIONSHIP CHECK

In AD1, the mass-to-CG relationship for single MDL payloads hard mounted to the EXPRESS Rack backplate, Middeck wire trays, or the SPACEHAB module shall conform to Table 4-VIA that abstracted as the following table shown.

X_{CG} inches	EXPRESS Ibm at 3 in. radius	MIDDECK Ibm		
	NA	X, 0, 0	± 0.5 Y & Z	± 1.0 Y & Z
14	51	54.1	50.2	46.8
13	55	57.6	53.4	49.8
12	60	61.8	57.2	53.2
11	65	66.3	61.4	57.1
0 to 10	72	70.0	66.4	61.6
				57.4

Note:

1. X_{CG} is measured from the EXPRESS Rack or SPACEHAB backplate mounting surface or from the Middeck wire tray structural interface. The Y_{CG} and Z_{CG} location is measured from the geometric center of the payload interface envelope.
2. Radius applies to Y_{CG} and Z_{CG} locations.
3. "EXPRESS" limits apply to both the EXPRESS transportation rack and the flight racks.
4. The 14 inch XCG is the maximum.
5. These limits are for launch and landing (i.e., transportation). Once on-orbit, these restrictions do not apply.
6. Allowable mass includes mounting hardware and adapter plate mass, but does not include power and data cable mass

Table 6-18: Maximum Mass and Center of Gravity for Express rack, Middeck, and Spacehab

From section 6.7 the mass of the FE model equals to 27.358 kg (**60.19 Ibm**) with the centre of gravity (0.001, 0.264, 0.131) m, based on the local coordinate of FE model.

In ACOP coordinate system (see chapter 6.3) the coordinate of the CoG are respectively 0.271m in x 0.216m in y and 0.099m in z (**10.67in, 8.5in and 3.9in**).

To verify the Express CoG limit: from the Table 6-14, the X of the CoG of ACOP FE model (in ACOP coordinate system) is less than 11 and the mass of ACOP FE model is less than 65lbm.

Only EXPRESS Rack requirements are applicable to ACOP. However, from the table above, it can be seen that the mass and CoG position satisfies also Middeck requirements. To verify the Middeck: the radius of the CoG Y and Z is limited in ± 0.5in; the X_{CG} 10.67inch is less than 11in, and the mass 60.19 Ibm is less than 61.4 Ibm.

The ACOP structure conforms to the mass-to-CG relationship required in AD1.

In the following figures the position of the CoG in ACOP coordinate system is presented.



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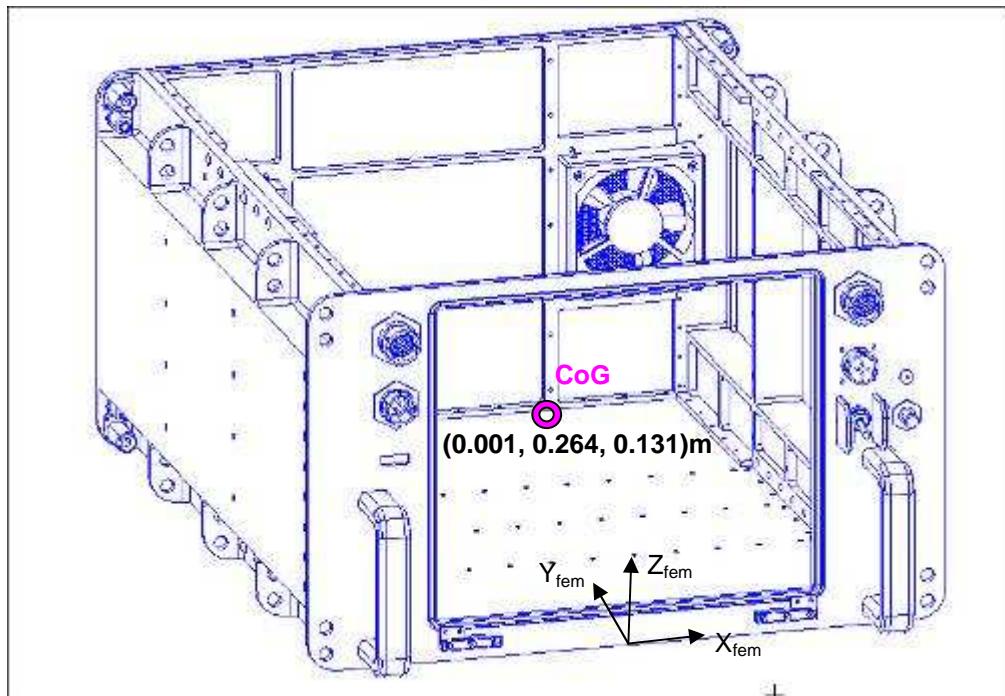


Figure 6-15: Mass-to-CG relationship of ACOP

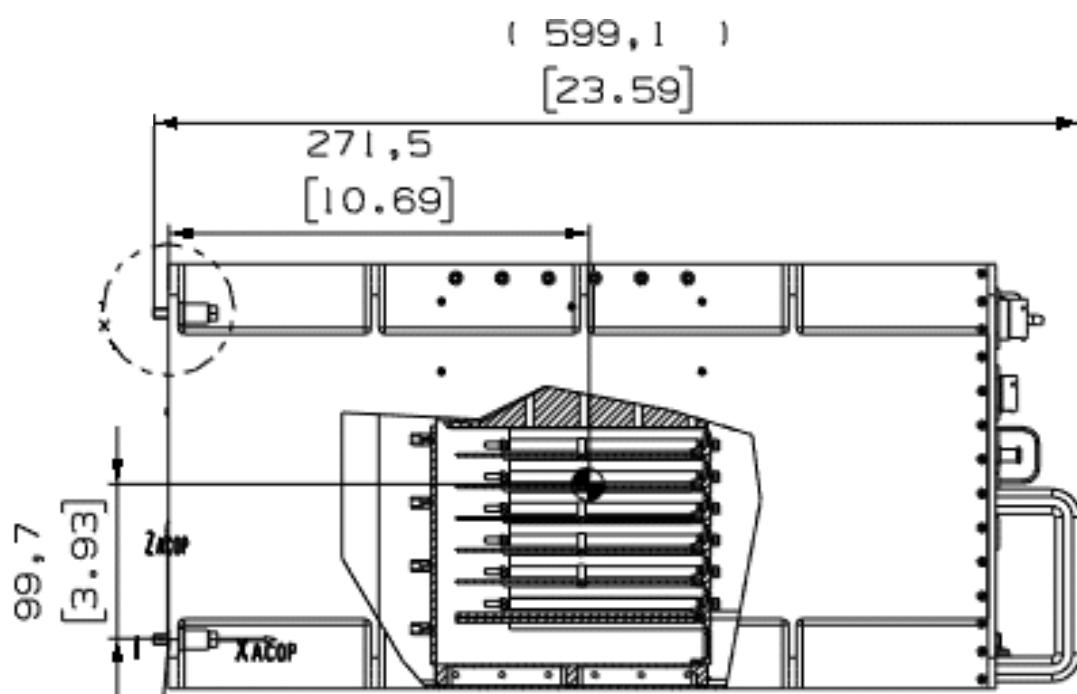


Figure 6-16: Mass-to-CG relationship of ACOP



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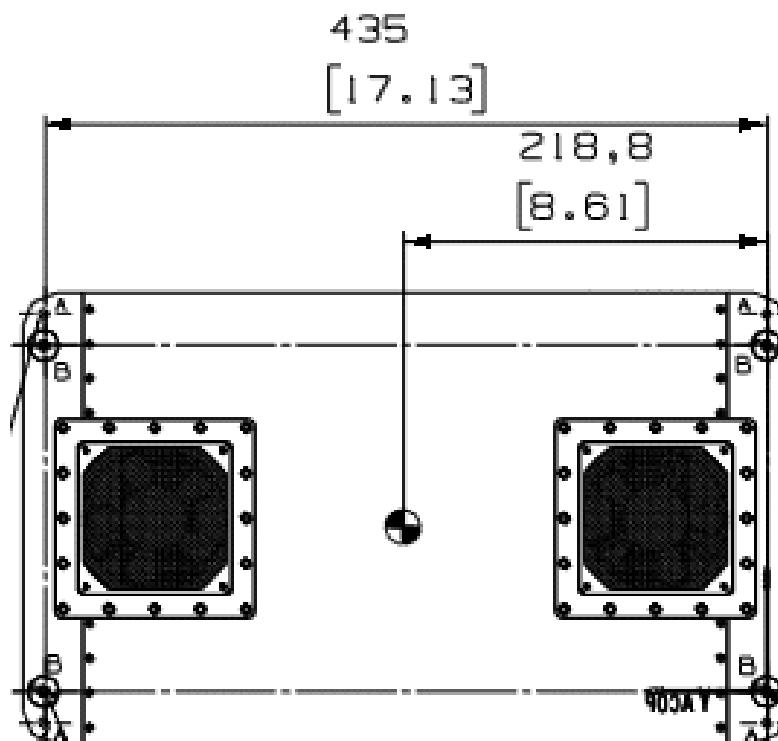


Figure 6-17: Mass-to-CG relationship of ACOP

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7. DIMENSIONING LOADS

The dimensioning load are calculated using the design loads for Express Rack and Middeck. The applicable are the EXPRESS Rack ones; the ones of the Middeck are used only as conservative assumption.

7.1 LOW FREQUENCY LOAD AND RANDOM VIBRATION LOAD

For ACOP structure, we combine the low frequency load factor list in AD1 section 4.1.2 and random vibration load spectrum list in section 4.3 by the methodology of load combination defined in AD16 section 4.2 to form load cases used in this report. The definition of load factors abstracted from AD1 and the combination of load factors are briefly described as following section.

7.1.1 EXPRESS RACK DESIGN LOAD FACTORS

Express Rack mounted payload hardware shall be designed to maintain positive margins of safety during liftoff and landing acceleration conditions as defined in the following table. EXPRESS Rack random vibration loads defined in Table 7-2 shall combine with the low frequency launch load factors.

FLIGHT EVENT	DESIGN LIMIT LOAD FACTORS, G's			COORDINATE SYSTEM
	X-AXIS	Y-AXIS	Z-AXIS	
Liftoff	± 7.70	± 11.60	± 9.90	ISPR ⁽¹⁾
Landing	± 5.40	± 7.70	± 8.80	

Table 7-1: Express rack design load factors

The low frequency loads at liftoff must be combined with loads due to the launch random vibration environment as directed in Table 7-2 and Figure 7-1.

PAYLOAD LOCATION	FREQUENCY	LEVEL
Backplate Mounted	20 Hz 20-80 Hz 80-120 Hz 120-2000 Hz 2000 Hz Composite	$0.01g^2/Hz$ $+3.0dB/oct$ $.04g^2/Hz$ $-4.0dB/oct$ $.00095g^2/Hz$ $3.5 g_{rms}$

Table 7-2: Express rack payload equipment high frequency random vibration launch environment

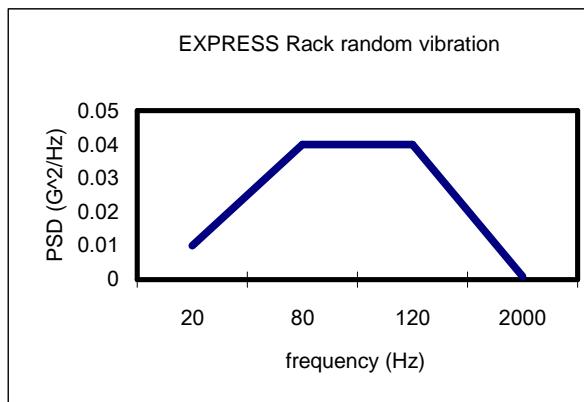


Figure 7-1: Power spectrum density (PSD) of EXPRESS Rack random vibration

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A normal modes solution with the boundary constrained in the flight configuration is evaluated in the PSD range (20~2000Hz). Identify all modes that have significant effective mass in each axis. The sum of the effective mass of the significant modes in each axis is added up to at least 80 percent of the total mass.

Calculate the random vibration load factor (RVLF) using the Miles formula for each significant mode: (Here Q=10.)

$$RVLF_i = 3\sqrt{\frac{\pi}{2} \cdot f_i \cdot Q \cdot PSD_i} \quad PSD_i = PSD_1(f_i/f_1)^{0.3322^*S}$$

Calculate the mass-weighted $RVLF_w$ for each $RVLF_i$. The significant effective masses of modes are list in Table 9.2.

$$RVLF_{i(w)} = RVLF_i \frac{m_{eff,i}}{\sum_i m_{eff,i}}$$

Root-sum-square all of the mass-weighted RVLFs.

$$RVLF = \sqrt{\sum_i (RVLF_{i(w)})^2}$$

By using the load combination criteria defined in AD16 section 4.2.1, load cases of EXPRESS rack are list in the following table.

LOAD CASE	DESIGN LIMIT LOAD FACTORS, G's		
	X-AXIS	Y-AXIS	Z-AXIS
Liftoff			
1~8	23.18, -21.22	± 11.60	± 9.90
9~16	± 7.70	± 14.72	± 9.90
17~24	± 7.70	± 11.60	± 22.01
Landing	± 5.40	± 7.70	± 8.80

Table 7-3: Combination of EXPRESS Rack load cases

Because load factors of landing case are smaller than those of lift-off load cases, landing load factors are not checked in this report.

7.1.2 MIDDECK DESIGN LOAD FACTORS

Middeck design load factors can be abstracted from AD1 Table 4-IB as follows. Middeck launch and landing load factors encompass the maximized transient and random vibration responses at liftoff and transient response at landing.

FLIGHT EVENT	DESIGN LIMIT LOAD FACTORS, G's			COORDINATE SYSTEM
	X-AXIS	Y-AXIS	Z-AXIS	
Liftoff	± 6.00	± 3.40	± 6.30	Crew Module
Landing	± 6.25	± 2.50	± 12.50	Crew Module

Table 7-4: Middeck design load factors

Load values are small than those in Express Rack load Table 7-1, and these loads can be neglected in analysis.

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The Middeck launch loads defined in the following table include the effects of random vibration.

FREQUENCY	LEVEL
20-150 Hz	+6.0 dB/oct
150-1000 Hz	.03 g ² /Hz
1000-2000 Hz	-6.0 dB/oct
Composite	6.5 g _{rms}

Legend: g_{rms} = root mean square acceleration in g's.
 dB/oct = decibels per octave
 Criteria are the same for all directions (X, Y, Z).
 Environment exposure duration = 7.2 sec/flight in each axis.

Table 7-5: Middeck payload equipment high frequency random vibration launch environment

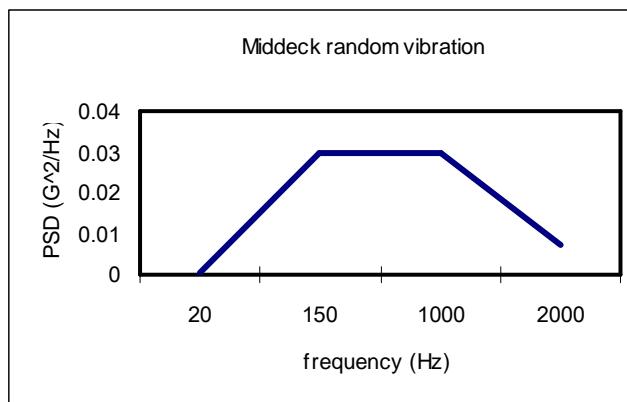


Figure 7-2: Power Spectrum Density of Middeck random vibration

7.2 MIDDECK EMERGENCY LANDING LOAD FACTORS

Another loads considered in this report are Middeck emergency landing loads listed in following table.

Load Case	ULTIMATE INERTIA LOAD FACTORS		
No.	X-Axis	Y-Axis	Z-Axis
25~30	+20.0 -3.3	+3.3 -3.3	+10.0 -4.4
Note:			
1. Sign convention follows that of the crew module coordinate system shown in SSP 52000-IDD-ERP Figure 4-1 2. Emergency landing load factors are ultimate. 3. Emergency landing load factors operate independently. Load factors are defined as opposite in sign from accelerations.			

Table 7-6: Middeck emergency landing load factors

7.3 ON-ORBIT LOADS

7.3.1 CREW-INDUCED LOADS

For ACOP structural verification, the crew-induced loads abstracted from AD1 Table 4-VII are listed as follows.

CREW SYSTEM OR STRUCTURE	TYPE OF LOAD	LOAD	DIRECTION OF LOAD
Handles	Push or pull concentrated on most extreme edge	222.6 N	Any direction
LCD panel	Load distributed over an area 4 inches by 4 inches (0.01 m^2)	556.4 N	Any direction

Table 7-7: Crew-induced load factors

There are three handles on the front panel. We apply the concentrated force at the centre of each handle for each plus or minus axis direction at a time and totally have 18 load cases numbered 31 to 48. The load case 49 is the normal pressure applied on the central region of the protection panel for LCD which applied area is defined in above table. When the crew changes the HDD, the unintentional load may occur in the maximum open-door angle configuration. The load case 50 is the normal pressure applied on the central region of the back-cover for LCD module which applied area is defined in above table.

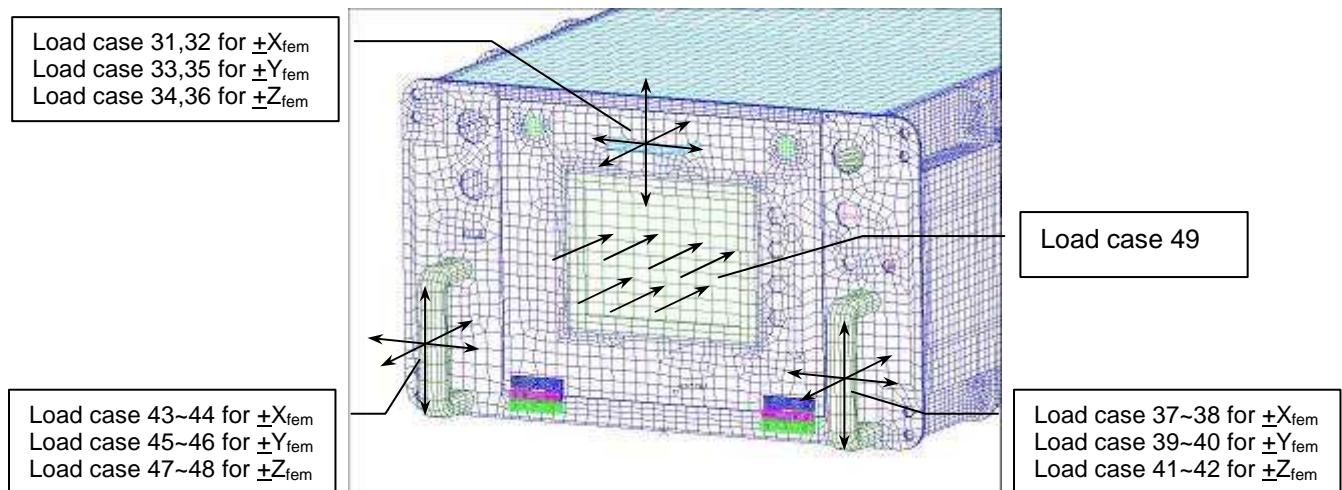


Figure 7-3: The direction of load 31~49

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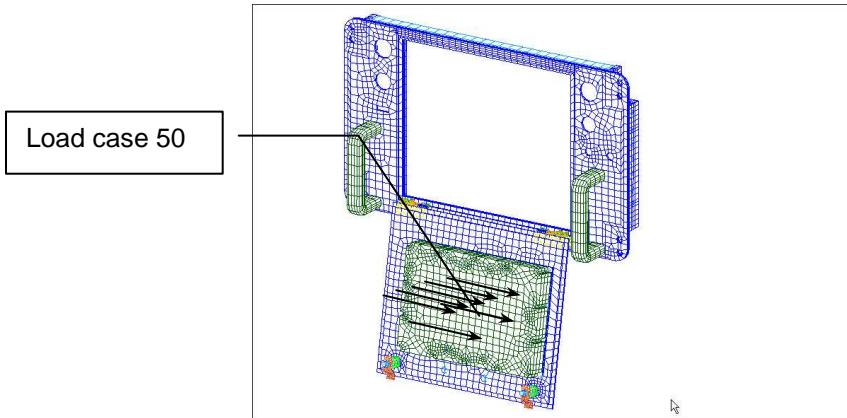


Figure 7-4: The direction of load 50

7.3.2 ON-ORBIT LOW FREQUENCY LOAD

According to AD1 only 0.2 g's acting in any direction for on-orbit low frequency load, it is much smaller than other loads and will not be considered in structural analysis.

7.4 DEPRESSURIZATION/RE-PRESSURIZATION LOAD

ACOP structure has two open windows on the backplate as air inlet and outlet. It maintains pressure balance in any time, and needs not consider depressurization and re-pressurization load.

7.5 THERMAL LOAD

There are no serious thermal loads defined in on ACOP structure. We use the material derating factor 0.97 for the maximum environment temperature 120 degree Fahrenheit to cover the thermal effect. The detail about derating factor is in chapter 8.2 .

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7.6 GROUND HANDLING LOAD

Ground handling loads defined in AD1 Table 4-XI is shown as follows.

TRANSPORTATION ENVIRONMENT	LIMIT LOAD FACTORS (g)			Load Occurrence
	LONGITUDINAL	LATERAL	VERTICAL	
Truck/Road	±3.5	±2.0	-3.5, +1.5	I, I
Barge/Water	±5.0	±2.5	-2.5	I
Dolly/Land	±1.0	±0.75	-2.0	I
Air Freight	±3.5	±3.5	-3.5	I
Fork lifting	±1.0	±0.5	-2.0	S
Hoisting	0	0	-1.5	I

Table 7-8: Ground handling load factors

These load factors are much smaller than other loads, and will be neglected in structural analysis.

In this report, we also consider the other unintentional ground handling load. The ACOP assembly is taken by only one handle as the following figure, the handle will be against the self-weight of ACOP assembly included four HDD inside. The joints of handle will be main check-points for safety. It is the 51st load case in this report.

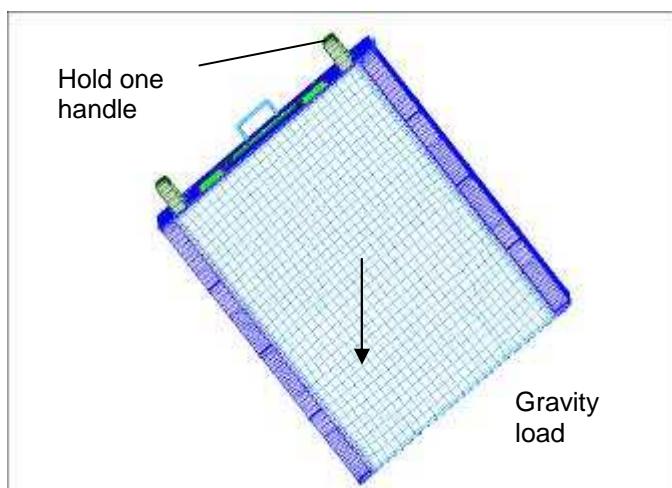


Figure 7-5: Only one handle held configuration

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7.7 TEST LOADS

According to the definition in AD16 chapter 7.2.2, we sum up four kinds of test loads for ACOP structural analysis.

7.7.1 QUALIFICATION FOR VIBRATION TEST (QVT) FOR PROTO-TYPE/QUALIFICATION TEST

The level of the QVT shall be the maximum expected flight environment that is the envelope of the random vibration load for EXPRESS Rack and Middeck shown in section 7.1.1 and 7.1.2. The test load factor for three main axes can be transformed by Miles formula described in section 7.1.1, and in order to cover the uncertainty in vibration test, 10% of vibration level of the main axis is considered for other two cross axes. The load factor for QVT is list in the following table.

Test Event	Test Load Factors, G's			Maximum Expected Flight Environment(Envelope of EXPRESS Rack and Middeck random vibration)		
	X-AXIS	Y-AXIS	Z-AXIS			
QVT	± 22.99 ± 1.82 ± 1.96	± 2.30 ± 18.23 ± 1.96	± 2.30 ± 1.82 ± 19.66	20- 80 Hz 80-120 Hz 120-150 Hz 150-1k Hz 1k-2k Hz	$+3.0 \text{ dB/Oct}$ $0.04 \text{ G}^2/\text{Hz}$ -4.0 dB/Oct $0.03 \text{ G}^2/\text{Hz}$ -6.0 dB/Oct	12.43 Grms

Table 7-9: The test load factor for QVT

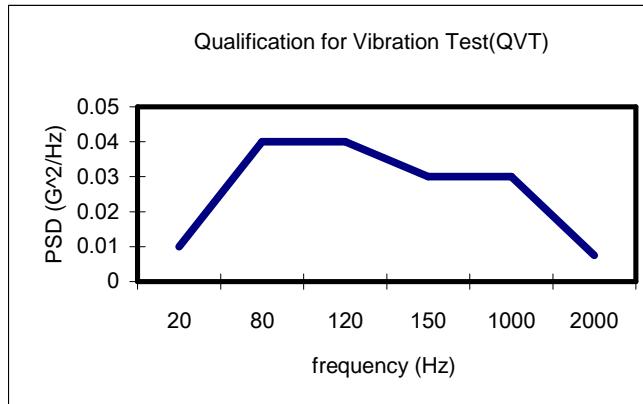


Figure 7-6: Power Spectrum Density of QVT

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7.7.2 QUALIFICATION FOR ACCEPTANCE VIBRATION TEST (QAVT) FOR PROTO-TYPE/QUALIFICATION TEST

The level of the QAVT shall be 2.3dB above the Acceptance Vibration Test (AVT) level defined in AD16 Table 7.2.2.3-1. By the same methodology in above section, the load factor for QAVT is list in the following table. The value of load factors of QAVT is much more than those of other test loads, and used as load case 52 to load case 75.

Test Event	Test Load Factors, G's			Acceptance Vibration Test (AVT) level + 2.3 dB
	X-AXIS	Y-AXIS	Z-AXIS	
QAVT (Load case 52~75)	± 34.59 ± 2.47 ± 2.69	± 3.46 ± 24.71 ± 2.69	± 3.46 ± 2.47 ± 26.87	20-80 Hz +3.0 dB/Oct 80-350 Hz 0.06793 G ² /Hz 350-2k Hz -3.0 dB/Oct 7.933 gRMS

Table 7-10: The test load factor for QAVT

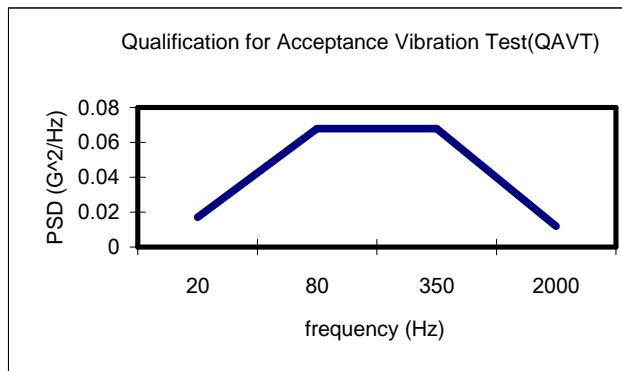


Figure 7-7: Power spectrum density of QAVT

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7.7.3 ACCEPTANCE TEST FOR FLIGHT HARDWARE

The level of this test shall be an envelope of the QVT level minus 2.3dB and the minimum AVT test level given in AD16 table 7.2.2.3-1. By the same methodology in above section, the load factor for Acceptance test for flight hardware is list in the following table.

Test Event	Test Load Factors, G's			Envelope of The QVT level - 2.3 dB and AVT
	X-AXIS	Y-AXIS	Z-AXIS	
Acceptance Test for Flight Hardware	± 26.55 ± 1.90 ± 2.06	± 2.66 ± 18.96 ± 2.06	± 2.66 ± 1.90 ± 20.62	The QVT level - 2.3 dB 20- 80 Hz +3.0 dB/Oct 80-120 Hz 0.0236 G ² /Hz 120-150 Hz -4.0 dB/Oct 150-1k Hz 0.0177 G ² /Hz <u>1k-2k Hz -6.0 dB/Oct</u> <u>9.548 Grms</u> AVT: 20-80 Hz +3.0 dB/Oct 80-350 Hz 0.04 G ² /Hz <u>350-2k Hz -3.0 dB/Oct</u> <u>6.064 Grms</u>

Table 7-11: The test load factor for Acceptance Test for Flight Hardware

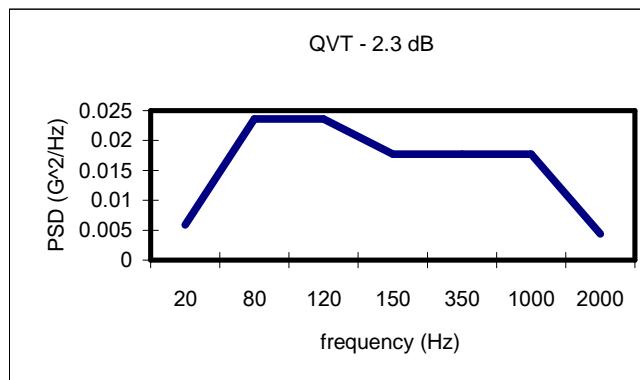


Figure 7-8: Power spectrum density of QVT minus 2.3dB

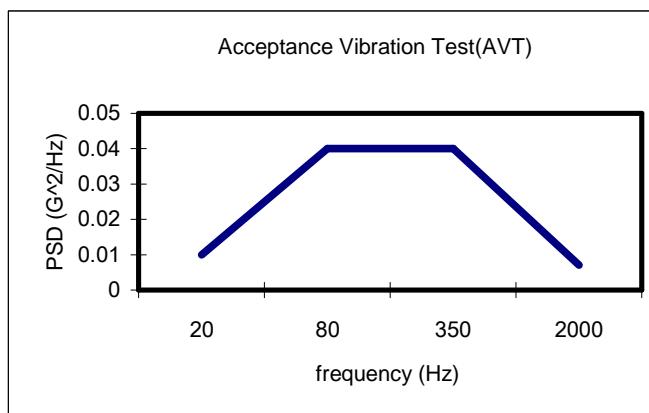


Figure 7-9: Power spectrum density of AVT

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7.7.4 PROTO-FLIGHT TEST

The level of the Proto–flight vibration test shall envelope the maximum expected flight environment and the minimum AVT test level given in AD16 table 7.2.2.3–1. By the same methodology in above section, the load factor for QVT is list in the following table. The level of QVT is shown as figure 7.7.1 and the level of AVT is shown as figure 7.7.3b.

Test Event	Test Load Factors, G's			Envelope of QVT and AVT level
	X-AXIS	Y-AXIS	Z-AXIS	
Proto-Flight Test	± 26.55 ± 1.90 ± 2.06	± 2.66 ± 18.97 ± 2.06	± 2.66 ± 1.90 ± 20.62	QVT: 20- 80 Hz +3.0 dB/Oct 80-120 Hz 0.04 G ² /Hz 120-150 Hz -4.0 dB/Oct 150-1k Hz 0.03 G ² /Hz <u>1k-2k Hz</u> -6.0 dB/Oct AVT: 20-80 Hz +3.0 dB/Oct 80-350 Hz 0.04 G ² /Hz 350-2k Hz -3.0 dB/Oct 6.064 Grms

Table 7-12: The test load factor for Proto-Flight Test

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7.8 SUMMARY OF LOAD CASES

After sum up the load cases described in above section, we have totally 75 load cases for ACOP structural analysis. The brief descriptions for load cases are list in the following table.

Load Case No.	Load Factors (G's)			Description for Loads	
	X-AXIS	Y-AXIS	Z-AXIS		
1~8	23.18, -21.22	\pm 11.60	\pm 9.90	Lift-off loads for Express Rack	
9~16	\pm 7.70	\pm 14.72	\pm 9.90		
17~24	\pm 7.70	\pm 11.60	\pm 22.01		
25~30	20.0 -3.3	3.3 -3.3	10.0 -4.4	Emergency landing load for Middeck (applied independently for each axis)	
31~36	222.6 N force on the small handle			Crew-induced push or pull concentrated force on the handle (applied for each axis)	
37~42	222.6 N force on the right large handle				
43~48	222.6 N force on the left large handle				
49	556.4 N distributed over an area 4 inches by 4 inches			Crew-induced pressure load on the protection panel for LCD module	
50				Crew-induced pressure load on the back-cover for LCD module(open door)	
51	1.0 G toward ground			Only one handle taken unintentionally, self-weight of ACOP applied	
52~59	\pm 34.59	\pm 3.46	\pm 3.46	Qualification for acceptance vibration test loads	
60~67	\pm 2.47	\pm 24.71	\pm 2.47		
68~75	\pm 2.69	\pm 2.69	\pm 26.87		

Table 7-13: The summary of load cases

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8. DIMENSIONING RULES

8.1 SAFETY FACTORS

The factors of safety used in ACOP structural analysis is summarized in Table 8.1.1 which conforms to AD1. Chapter 4.

FACTOR OF SAFETY				
CATEGORY		YIELD	ULTIMATE	SEPARATION
Metallic Structures	Analysis for nominal configuration	1.25	2.0	---
	Analysis for fail-safe configuration	---	1.0	---
Non-metallic parts	Polycarbonate (Lexan LCD protection layer)	---	2.0	---
	Acrylic resin (LCD panel)	---	2.0	---
Joints	Nominal configuration	1.25	2.0	1.2
	Fail-safe configuration	---	1.0	---

Table 8-1: Factors of Safety for ACOP Structural Analysis

8.2 TEMPERATURE DERATING FACTOR

The tensile yield strength for aluminum (7075-T7351 or 6061-T6) is reduced by a factor of 0.97 when the reference temperature is raised to 120 ° F that defined in AD1 Table 5-I. Material properties at the elevated temperature are obtained from MIL-HDBK-5H.

8.3 MARGINS OF SAFETY FOR STRUCTURE

A margin of safety of structure is defined as the decimal fraction as defined in the equation below:

$$MoS_u = \frac{P_u}{P \times FS_u} - 1 \quad MoS_y = \frac{P_y}{P \times FS_y} - 1$$

Where:

FSu = Ultimate Factor of Safety

FSy = Yield Factor of Safety

P = Limit Load (or stress) calculated in the analysis

Pu = Load (or stress) at which material failure will occur

Py = Load (or stress) at which material yielding will occur

MoSu = Margin of Safety against ultimate failure

MoSy = Margin of Safety against material yielding

It is required that MoS are positive for all structures in all combined loading conditions.

A detail description of margin of safety of fastener calculation will be in the chapter relevant to joint analysis.

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9. DYNAMIC ANALYSIS

In this section the definition of dynamic verification and results of natural frequencies, mode shapes and effective masses are included. The dynamic analysis is performed by the first type of FE model defined in section 6.5 .

9.1 DEFINITION OF DYNAMIC VERIFICATION

In AD1 section 4.1.1, the minimum natural frequency of hard mounted payloads is required by:

- (1) EXPRESS payload components hard mounted during launch and landing flight events shall have a first primary natural frequency equal to or exceeding 35 Hz when rigidly constrained at the component to rack interface.
- (2) Middeck payload components hard mounted during launch and landing flight events shall have a first primary natural frequency equal to or exceeding 30 Hz with respect to the Orbiter attachment interface.

9.2 EIGENFREQUENCIES AND MODE SHAPES

The first natural frequency is **128.97** Hz and complies with the requirement listed in the previous section. The first 60 natural modes of ACOP crate are:

Mode	Freq [Hz]	Mode	Freq [Hz]	Mode	Freq [Hz]
1	128.97	21	250.28	41	342.12
2	157.16	22	250.61	42	373.98
3	168.38	23	250.72	43	378.02
4	173.53	24	257.99	44	380.05
5	185.16	25	273.83	45	381.70
6	193.81	26	276.39	46	383.89
7	194.80	27	288.14	47	389.42
8	195.12	28	298.65	48	396.86
9	195.80	29	313.51	49	404.79
10	214.61	30	313.74	50	407.99
11	220.98	31	314.06	51	409.52
12	223.00	32	315.24	52	422.51
13	224.47	33	315.61	53	427.62
14	225.35	34	316.09	54	430.78
15	226.43	35	317.06	55	431.67
16	229.84	36	327.07	56	432.44
17	230.52	37	330.39	57	433.75
18	238.20	38	336.79	58	449.22
19	244.36	39	337.71	59	450.34
20	245.40	40	338.15	60	455.36

Table 9-1: FIRST 60 MODES FREQUENCIES



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The more important modes with large effective mass are shown as follows.

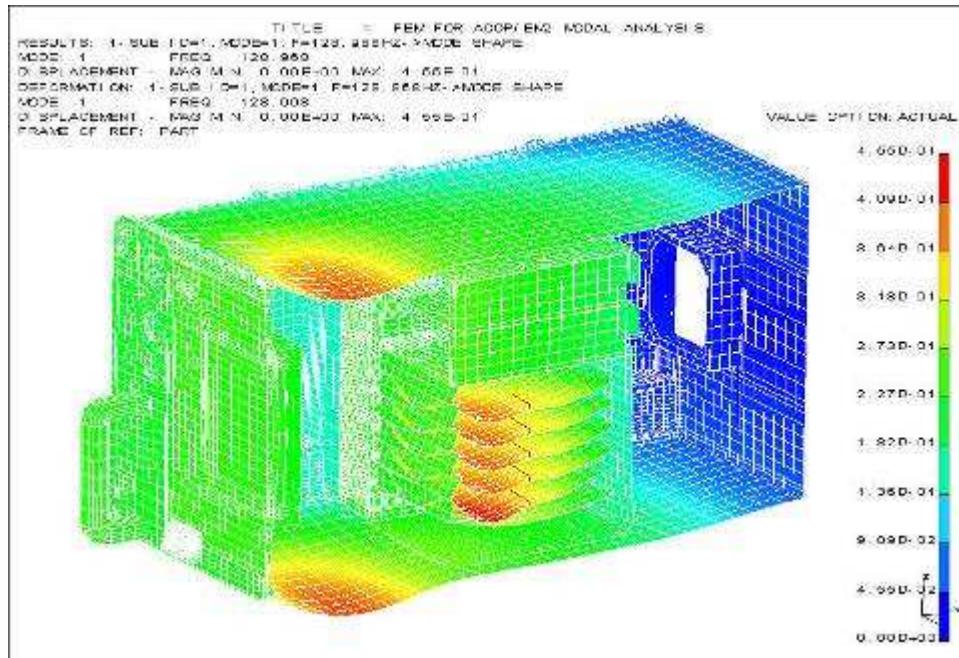


Figure 9-1: The 1st mode shape (128.97Hz, 1st global mode in Z_{fem} direction)

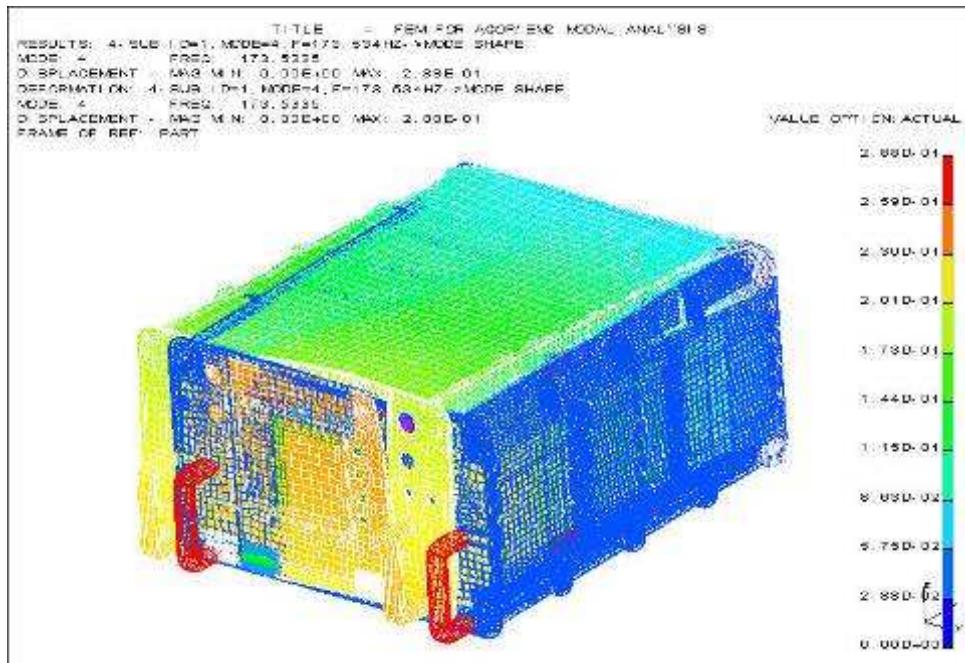


Figure 9-2: The 4th mode shape (173.53Hz, Global mode in X_{fem} direction)



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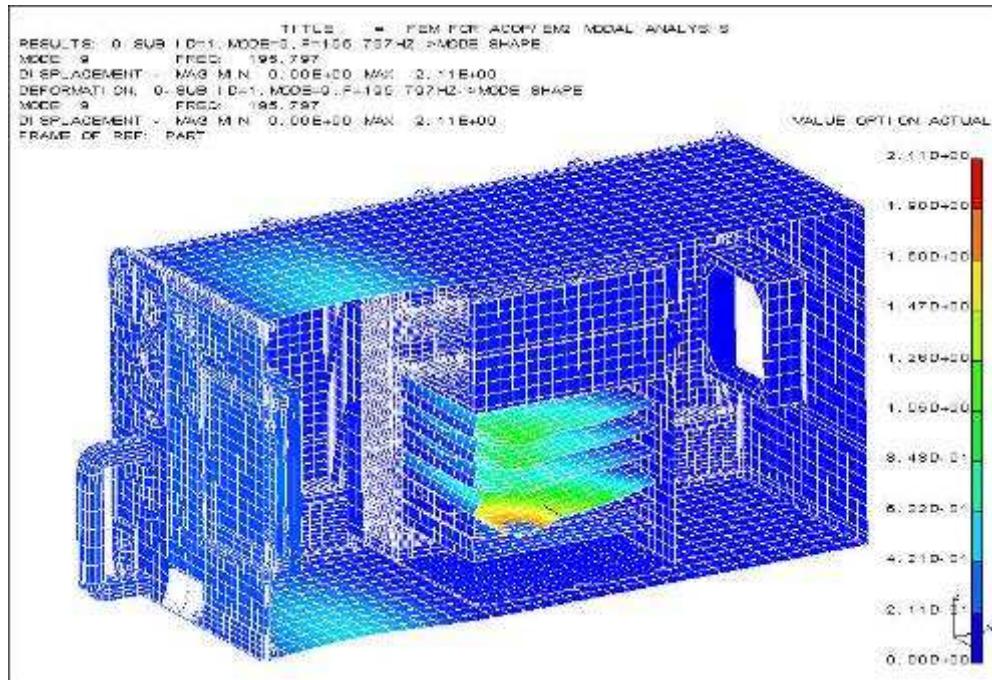
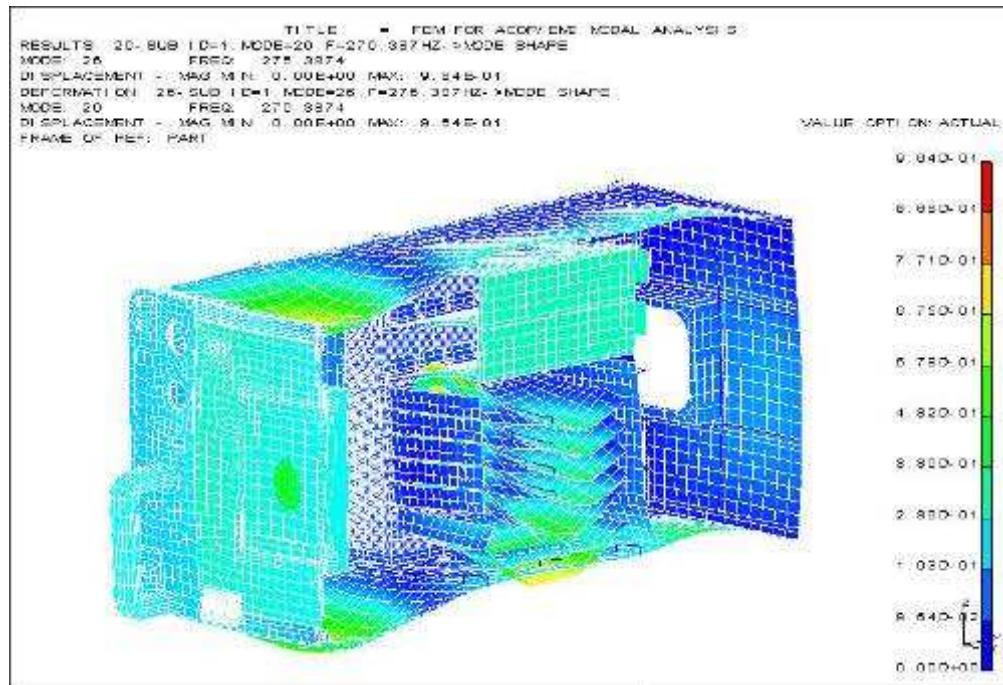


Figure 9-3: The 9th mode shape (195.8Hz, Electronic boards bending mode)

Figure 9-4: The 26th mode shape (276.39Hz, 2nd global mode in Z_{fem} direction)



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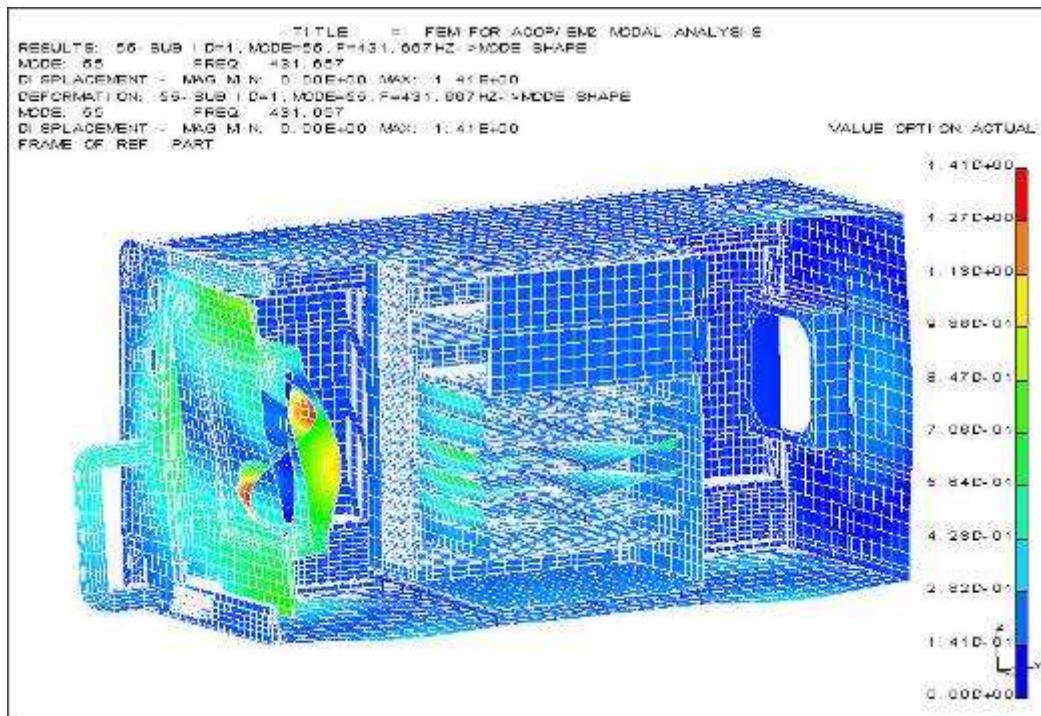
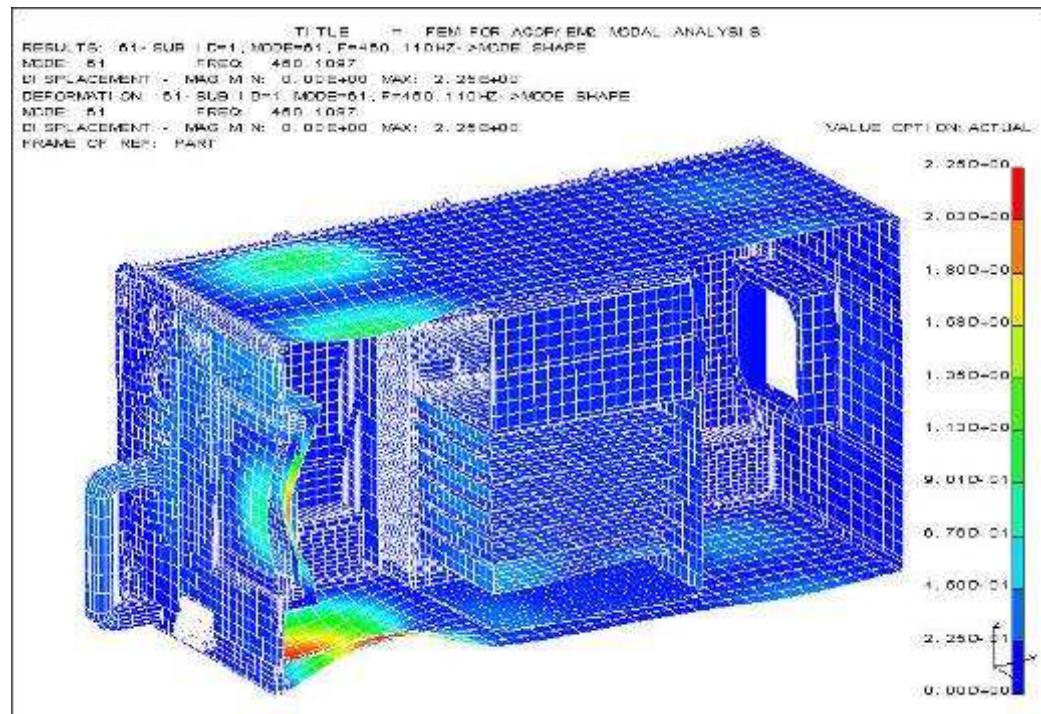
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Figure 9-5: The 55th mode shape (431.67Hz, Front door deflection mode)Figure 9-6: The 61st mode shape (460.11Hz, The top, bottom plate and LCD deflection mode)

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9.3 EFFECTIVE MASS

The following table shows the modes with the significant effective mass added up to 80 % of the total mass in each axis.

MODE	FREQUENCY (HZ)	X FRACTION	X EFF. MASS	Y FRACTION	Y EFF. MASS	Z FRACTION	Z EFF. MASS
1	128.97					76.33%	20.883
2	157.16			2.76%	0.756		
4	173.53	84.74%	23.182				
5	185.16					0.23%	0.062
9	195.80					0.86%	0.237
10	214.61			4.55%	1.245		
16	229.84			2.44%	0.668		
17	230.52					0.47%	0.128
18	238.20					0.48%	0.132
24	257.99					0.21%	0.058
25	273.83			4.97%	1.361		
26	276.39					1.03%	0.283
37	330.39					0.21%	0.056
48	396.86					0.25%	0.070
50	407.99			2.01%	0.551		
52	422.51			6.22%	1.702		
55	431.67			40.34%	11.037		
61	460.11			8.51%	2.328		
62	466.06			1.86%	0.508		
65	472.72			1.84%	0.504		
76	489.98			5.19%	1.420		
	SUM	84.74%	23.182	80.71%	22.080	80.08%	21.908

Table 9-2: Selection of the significant effective mass



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The modes with significant effective mass are shown as Figure 9-7. The cumulative effective masses for all axes are shown as Figure 9-8.

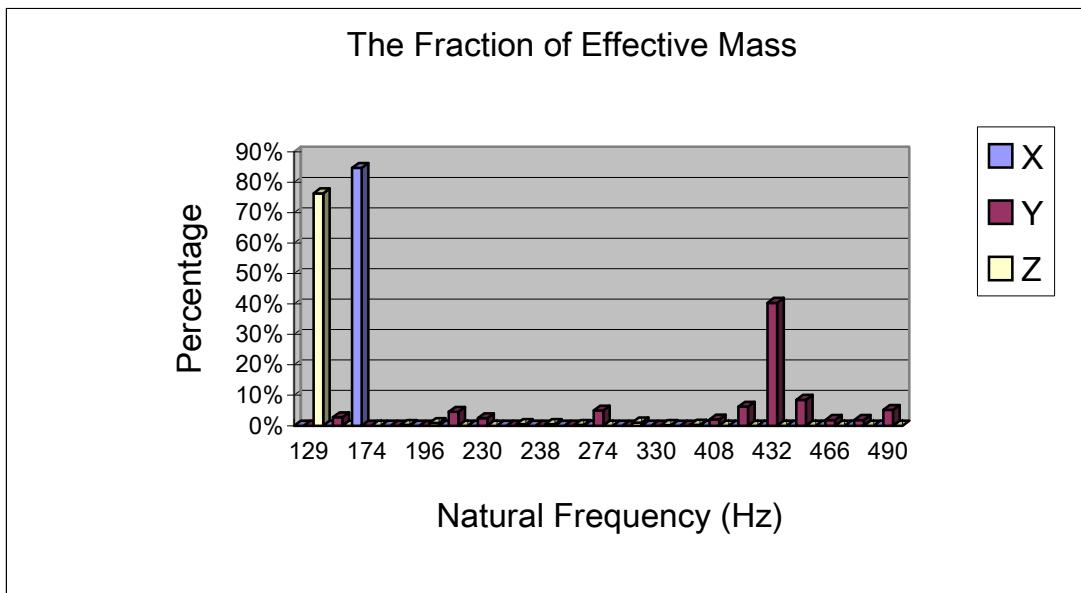


Figure 9-7: Distribution of the modes with significant effective mass

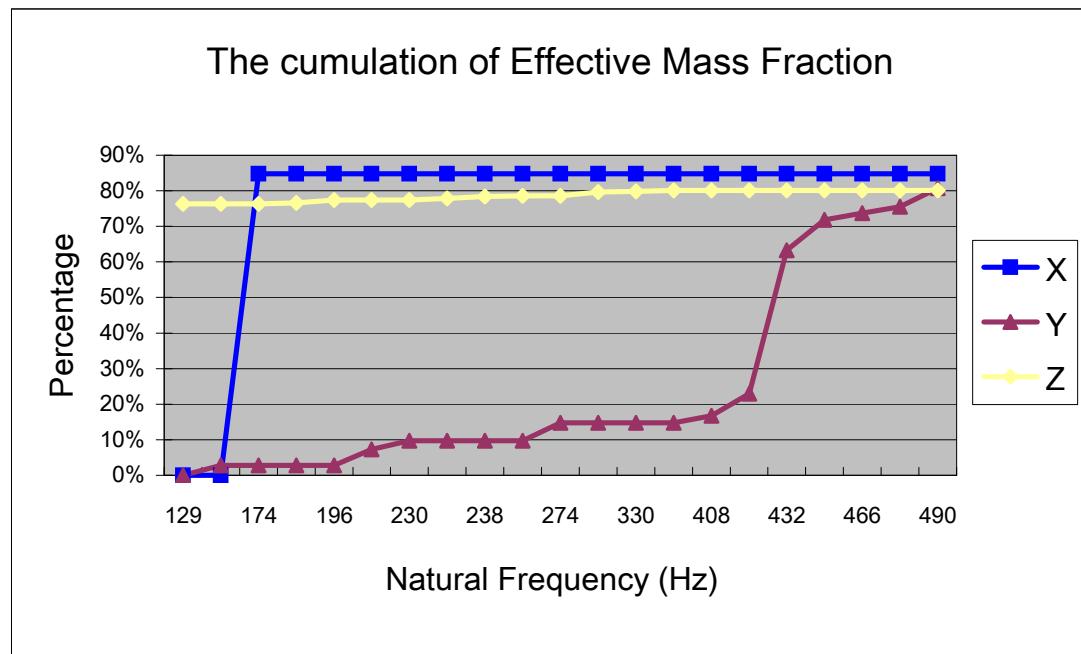


Figure 9-8: Cumulative effective masses for all axes

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10. STATIC ANALYSIS

This section presents the results of static analysis of ACOP crate in the load calculated in section 7.8 . The maximum displacements and stresses of each part of ACOP crate are listed and shown as followings.

10.1 DISPLACEMENT ANALYSIS

The summary of maximum displacements of each part is listed in Table 10-1. The following figures present the fringe of the displacement.

MAXIMUM DISPLACEMENT (mm)					
Part item	Max. disp.	Critical load case	Description of Load	Occurred Location	Figure
Locker	0.63	72	QAVT test Load (2.69, -2.69, 26.87) G's.	Top plate bending toward Z_{fem} direction	Figure 10-3
Chassis	0.47	72	QAVT test Load (2.69, -2.69, 26.87) G's.	Joint on the left-bottom of backplane	Figure 10-4
Electronic Boards	0.60	73	QAVT test Load (2.69, -2.69, -26.87) G's.	Centre of front edge of SBC board	Figure 10-5
Hinge & adapters	0.50	71	QAVT test Load (-2.69, 2.69, -26.87) G'S.	The left hinge and adapters	Figure 10-6
Latch	0.83,	55,	QAVT test Load 55 --(-34.59, 3.46,-3.46)G for X_{fem} direction,	Left latch	Figure 10-7
	0.51	71	QAVT test Load 71--(-2.69, 2.69, -26.87)G for Z_{fem} direction		
LCD	0.54	66	QAVT test Load (-2.47, -24.71, 2.47)	Center of LCD acrylic resin panel	Figure 10-8
Lexan	1.78	49	crew induced pressure on Lexan protection layer	Center of Lexan protection layer	Figure 10-9
Back cover of LCD	1.85	50	crew induced pressure on LCD back cover in the open door configuration	Center of LCD back cover	Figure 10-9
Door	11.7	50	crew induced pressure on LCD back cover in the open door configuration	Top edge of door	Figure 10-10

Table 10-1: Maximum displacement of each part

From the previous Table we find most maximum displacements occurred in each part are induced by QAVT test loads. They are quiet small in the locker, chassis, electronic boards and hinge.

The maximum displacements of X_{fem} and Z_{fem} direction in the latch are also quite small. The tolerant distance in the contact region between the pawl of latch and front panel is 4mm for X_{fem} direction and 8mm for Z_{fem} direction. The maximum 0.83mm for X_{fem} direction and 0.51mm for Z_{fem} direction in the latch will maintain contact well.



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The maximum displacement of LCD panel is just 0.54mm that could not touch the Lexan protection layer. The maximum displacement of Lexan layer 1.78mm due to crew-induced pressure load is smaller than the gap distance(3mm) shown in figure 10.1.1, and also could not touch the LCD panel. The designed protection is good.

The maximum displacement of back cover of LCD 1.85mm due to crew-induced pressure load is smaller than the gap distance(9mm) shown in figure 10.1.1, and also could not touch the LCD board. The designed protection is good.

When the door takes the crew-induced pressure in the open configuration, the maximum displacement of top edge of door will reach to 11.7mm is still smaller than the design gap 17.72mm shown in figure 10.1.2 and keep away from the vertical plane.

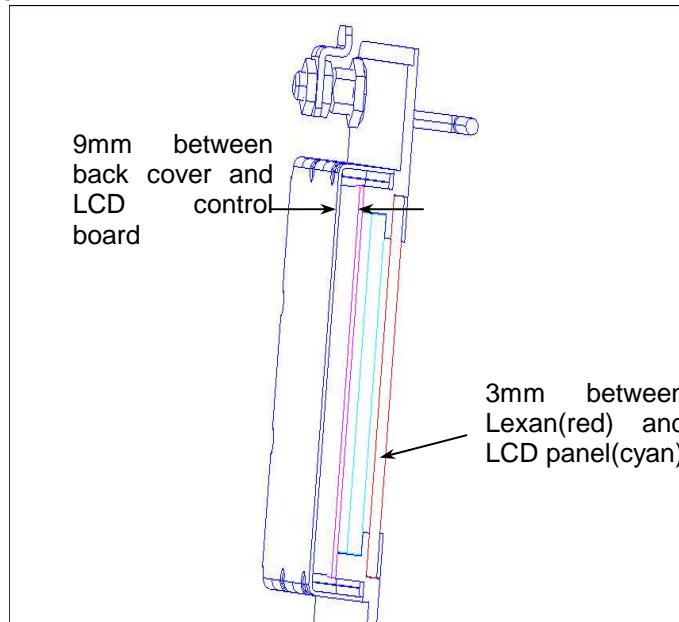


Figure 10-1: The distance of gap in the LCD module

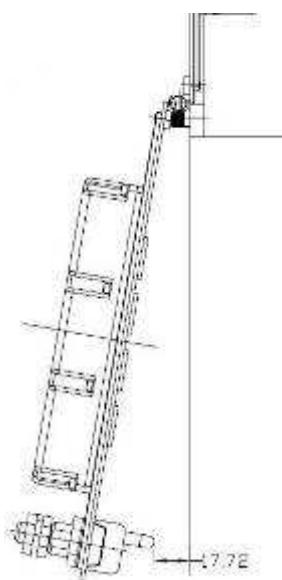


Figure 10-2: The distance between handle and vertical plane in the open door configuration



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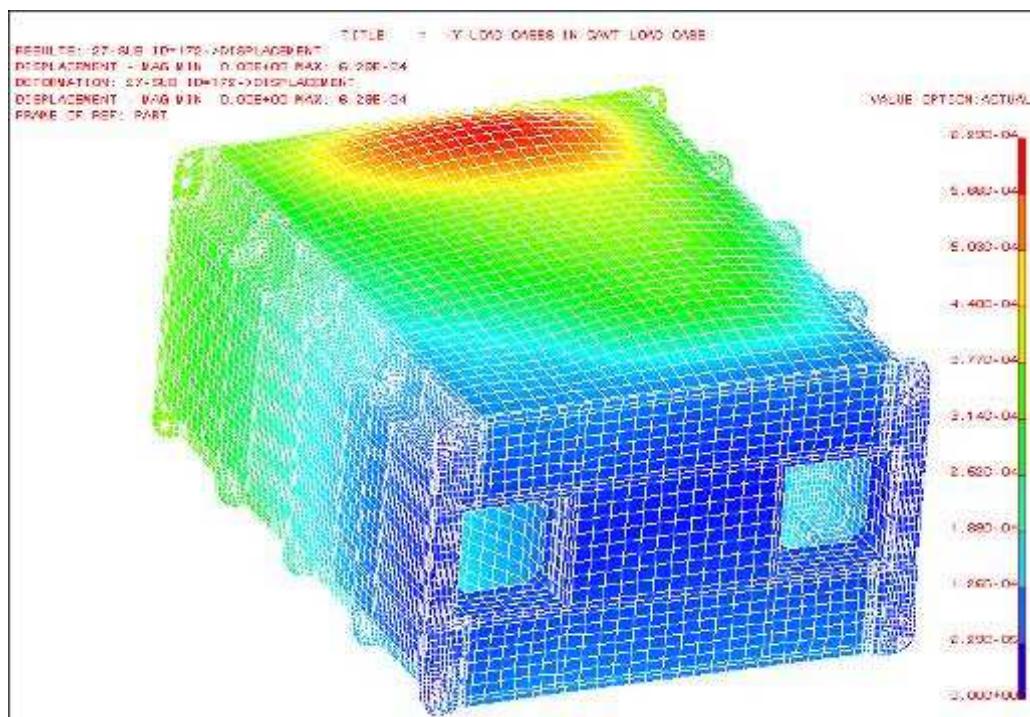


Figure 10-3: Maximum displacement of locker LC 72

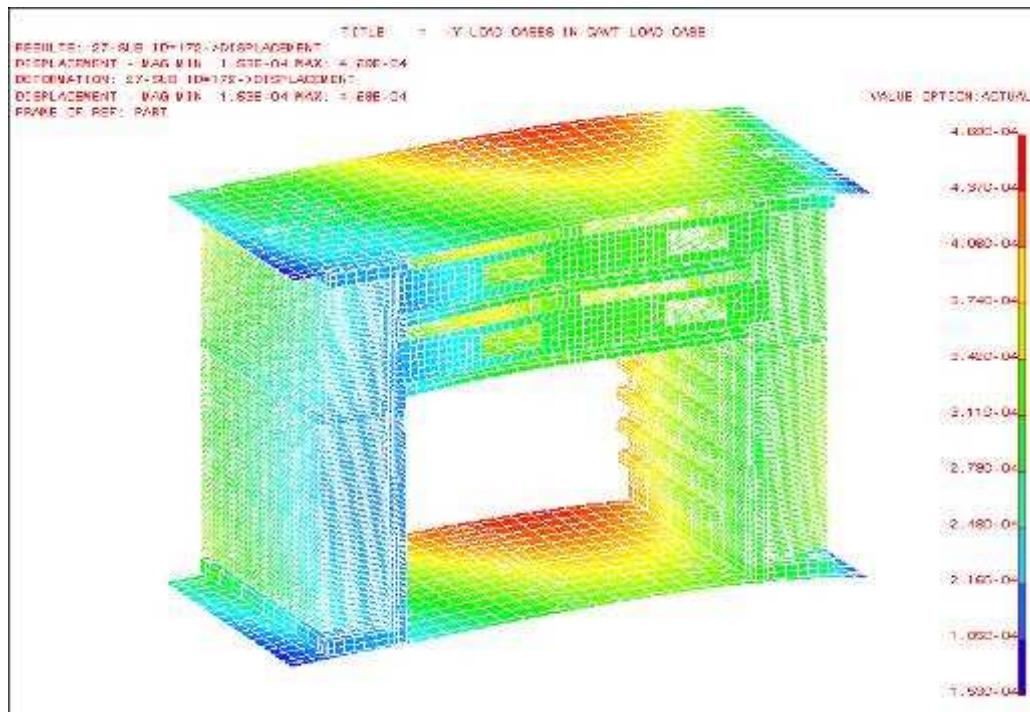


Figure 10-4: Maximum displacement of chassis LC 72

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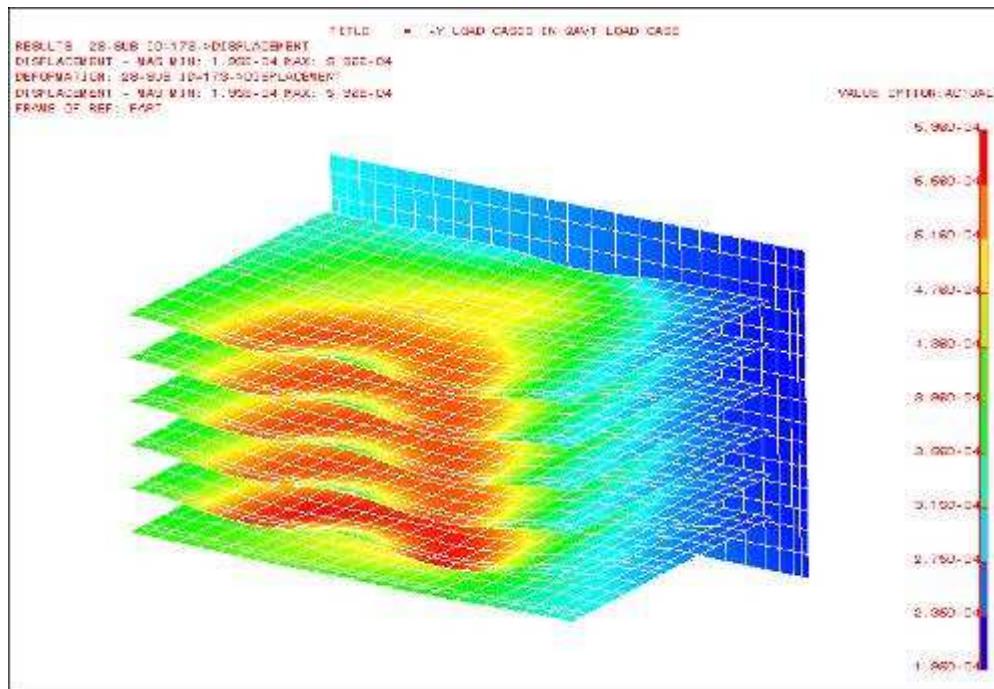


Figure 10-5: Maximum displacement of electronic boards LC 73

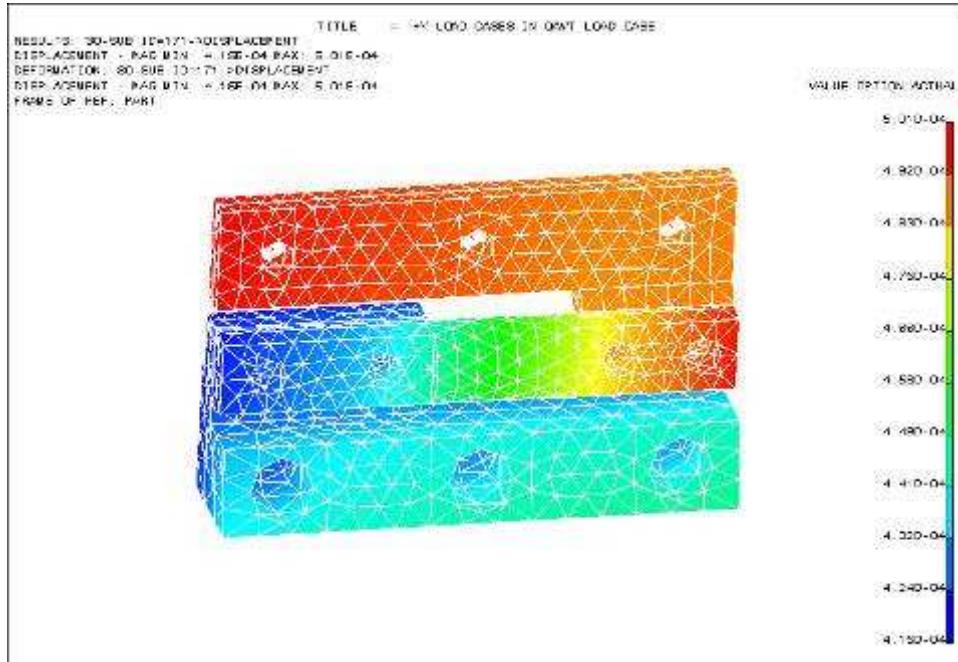


Figure 10-6: Maximum displacement of hinge and adapters LC 71



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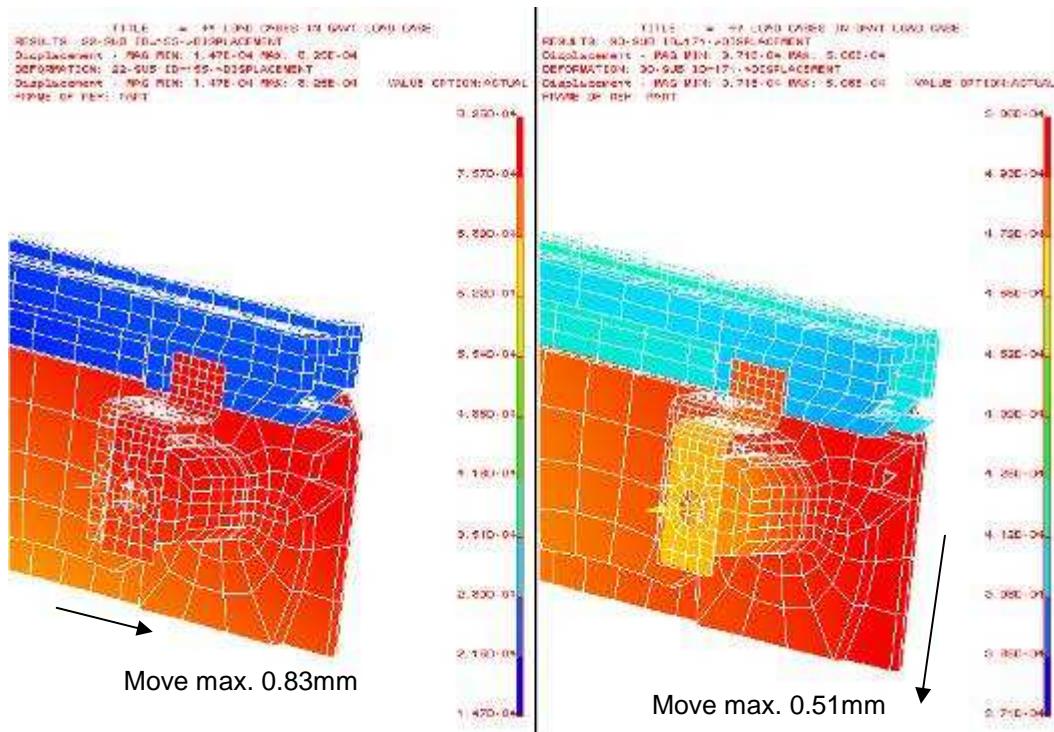


Figure 10-7: Maximum displacement of latches LC 55 for X_{FEM} dir and LC 71 for Z_{FEM}

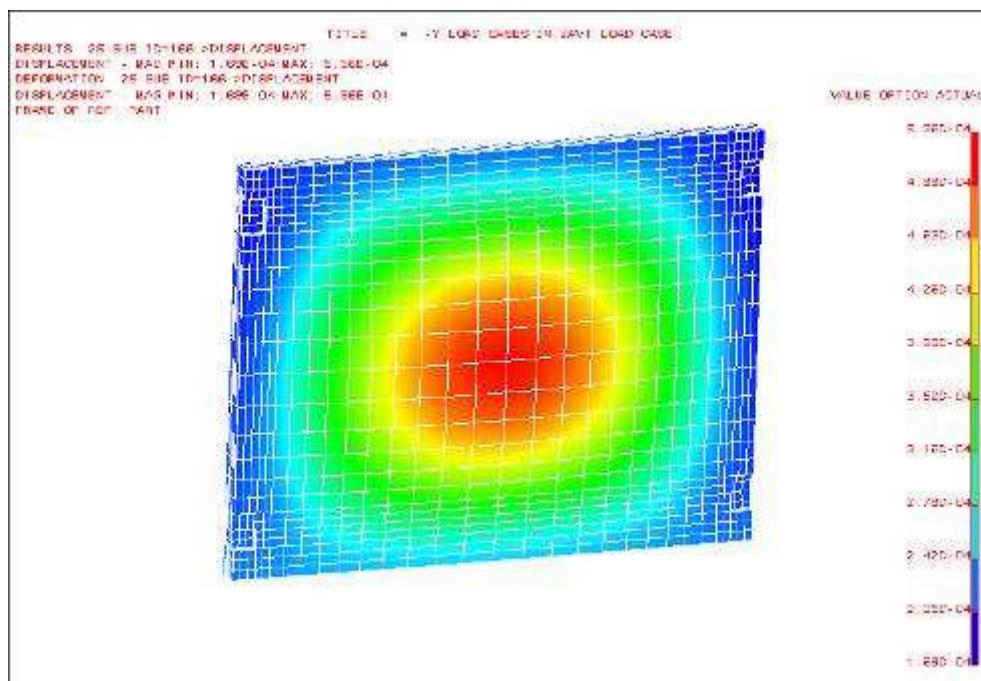


Figure 10-8: MAXIMUM DISPLACEMENT OF LCD LC 66



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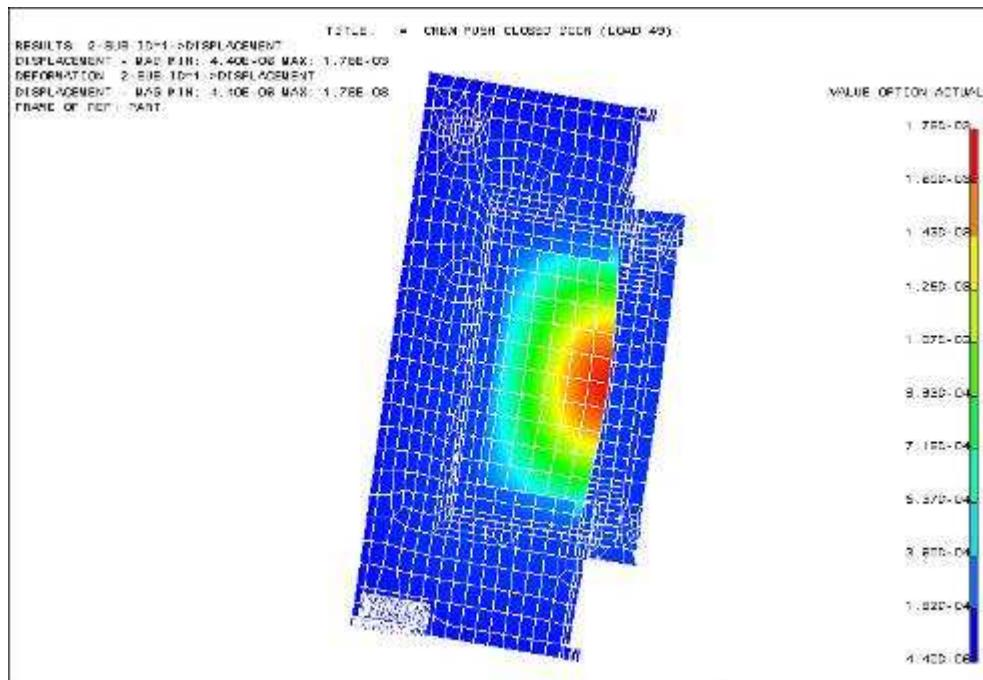


Figure 10-9: Maximum displacement of LCD LEXAN protection layer LC 49

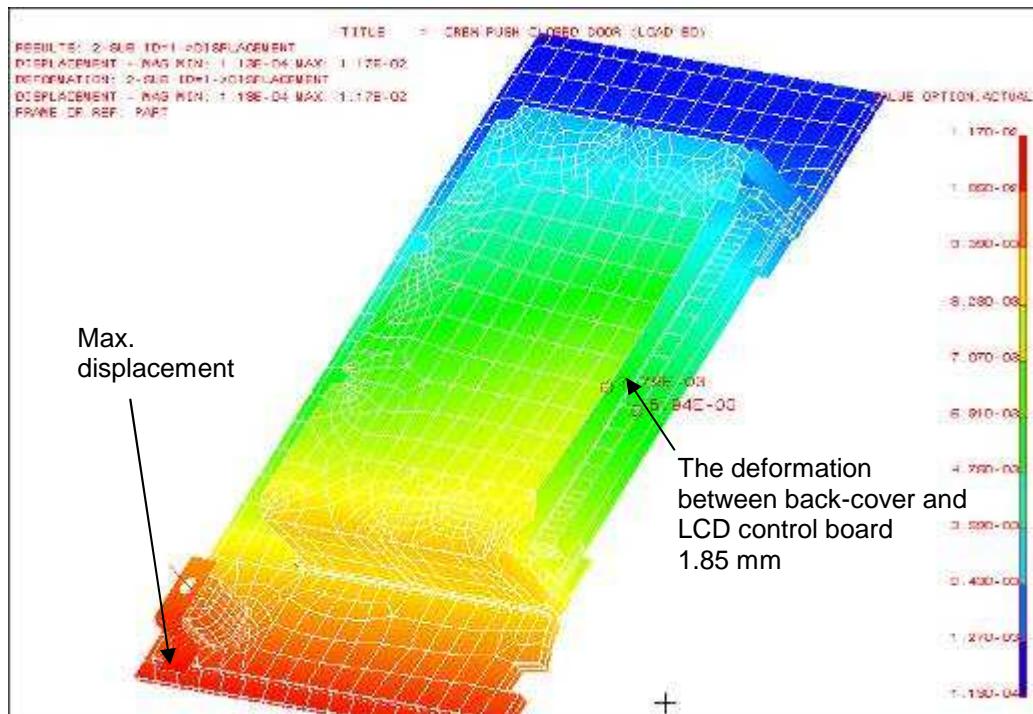


Figure 10-10: Maximum displacement of door.occurred in LC 50

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10.2 STRESS ANALYSIS

The summary of maximum displacements of each part is listed in Table 10-1. The following figures present the fringe of the displacement.

The maximum von Mises stresses of each part are listed in the Table 10-2; the following figures present the fringe of the von Mises stresses

Maximum stress (MPa)					
Item	Max. stress	Critical load case	Description of Load	Occurred Location	Figure
Locker	176.	21	Express Rack lift-off load (7.7, -11.6, 22.01) G's	Edge of screw hole at left-bottom corner	FIGURE 10-11
Chassis	57.8	58	QAVT test Load (-34.59, -3.46, 3.46) G's.	Joint on the left-bottom of backplane	Figure 10-12
Electronic Boards	5.18	73	QAVT test Load (2.69,-2.69, -26.87) G's.	Centre of front edge of SBC board	Figure 10-13
PB-Heat Sink plate	72.1	73	QAVT test Load (2.69,-2.69, -26.87) G's.	Near right card lock region	Figure 10-14
Hinge	138	52	(34.59, 3.46,3.46) G's.	Left hinge internal surface	Figure 10-15
Hinge adapters	499	50	crew induced pressure on the back cover of LCD in the open door configuration	At edge of upper hinge adapter	Figure 10-16
Latch Pawl	55.9	59	QAVT test Load (-34.59, -3.46, -3.46) G's.	Near bending region of pawl	Figure 10-17
Latch housing	24.1	59	QAVT test Load (-34.59, -3.46, -3.46) G's.	Near the intersection of housing and door	Figure 10-17
LCD housing	28.3	66	QAVT test Load (-2.47, -24.71, 2.47)	Edges of LCD housing	Figure 10-18
Lexan	6.11	49	crew induced pressure on Lexan protection layer	Centre of Lexan protection layer	Figure 10-19
Door	155.	50	crew induced pressure on LCD back cover in the open door configuration	At centre of upper edge of back cover	Figure 10-20
Front Panel	90.3	20	Express Rack lift-off load (-7.7, 11.6, -22.01) G's	Near top of the left side of door edge	Figure 10-21

Table 10-2: Maximum stress of each part



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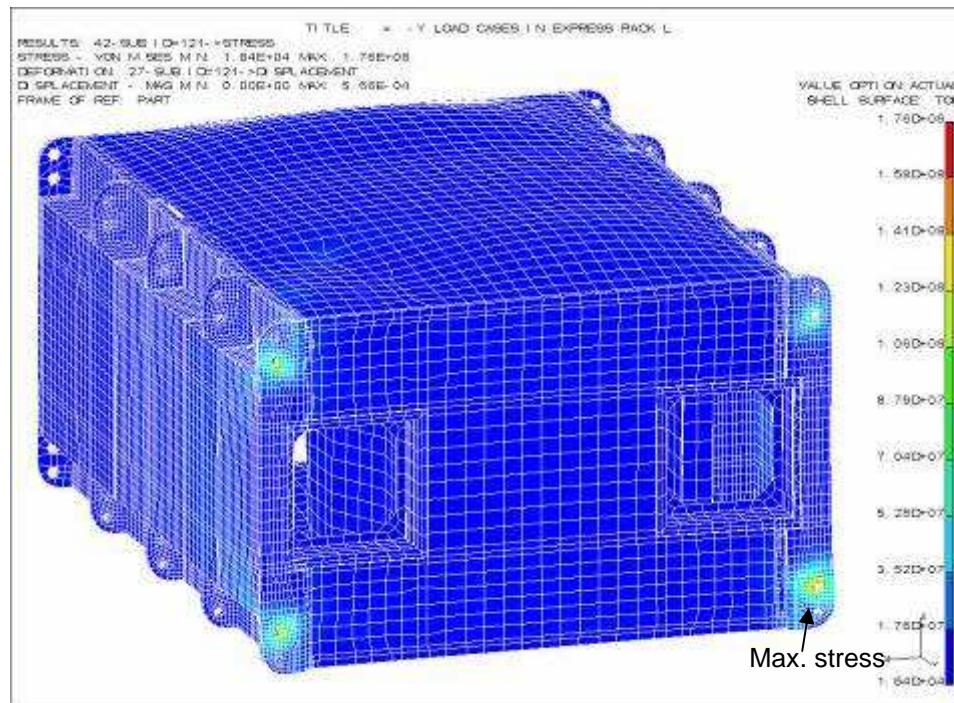


Figure 10-11: Maximum stress in Locker, 176 MPa occurred in load case 21

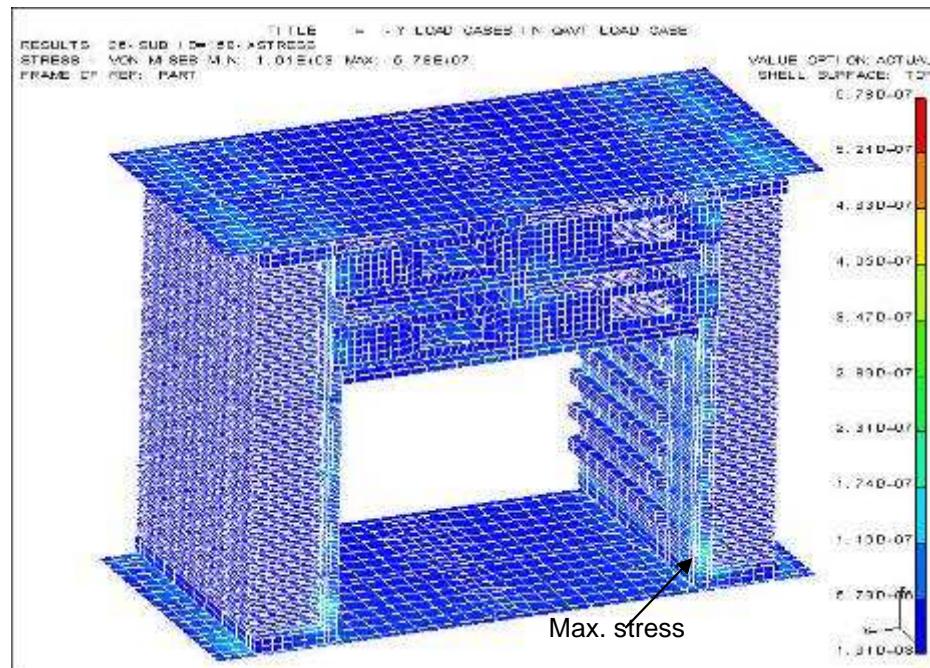


Figure 10-12: Maximum stress in chassis, 57.8 MPa occurred in load case 58

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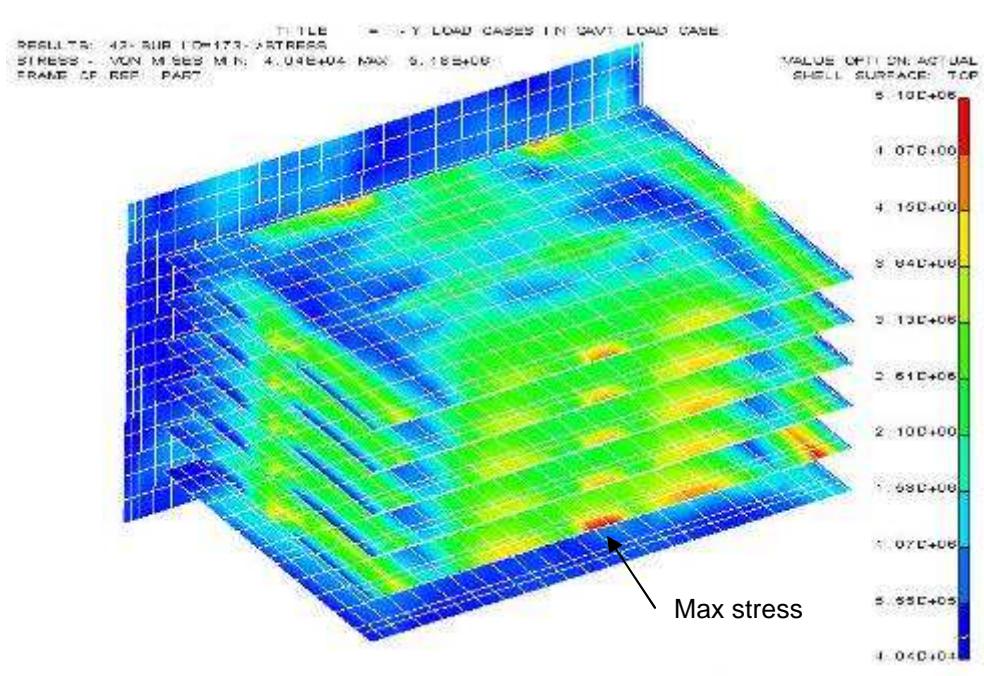


Figure 10-13: Max stress in electronic boards, 5.18 MPa occurred in load case 73

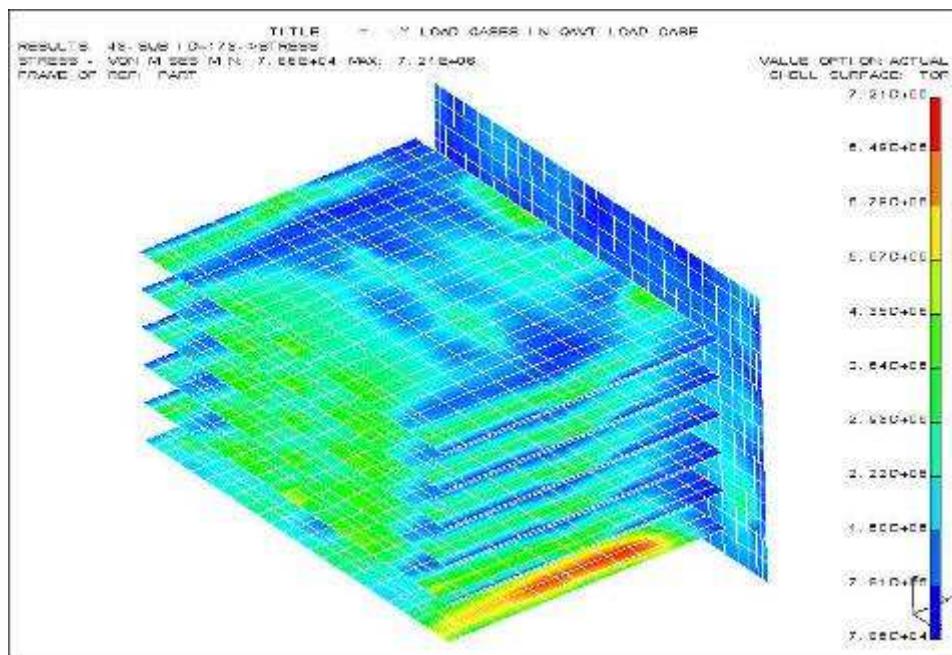


Figure 10-14: Max stress in heat sink plate of power board, 72.1 MPa occurred in load case 73



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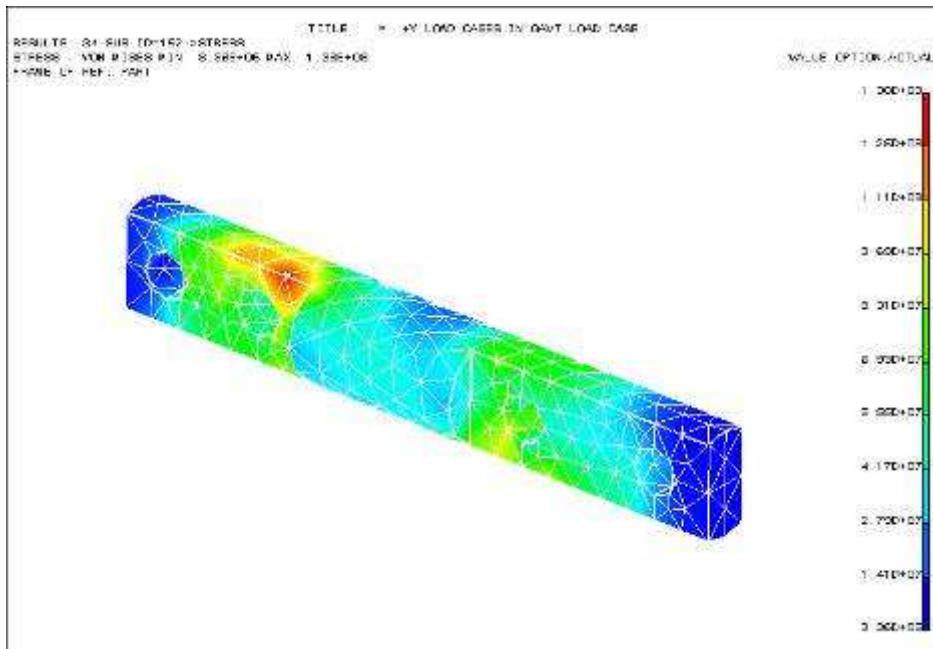
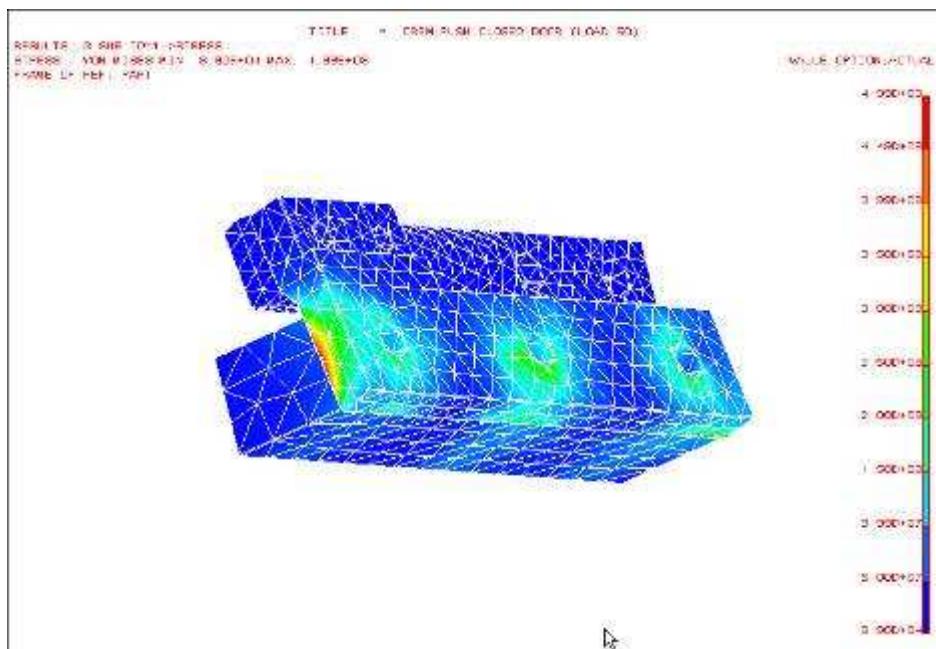


Figure 10-15: Maximum stress in hinge, 138 MPa occurred at left hinge internal surface in load case 52





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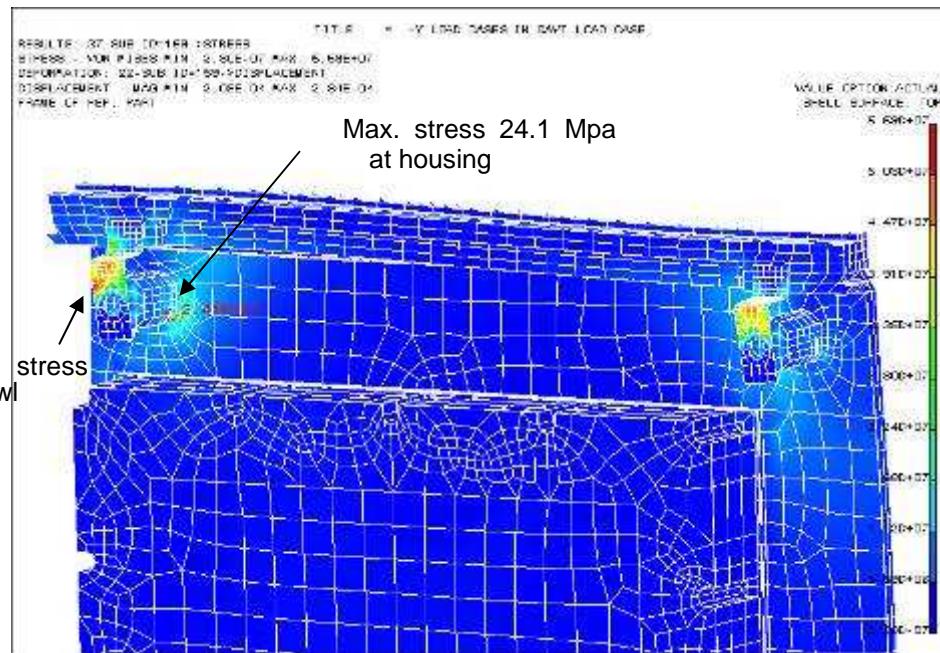


Figure 10-17: Maximum stress in Latch, 55.9 MPa occurred at Pawl of latch in load case 59

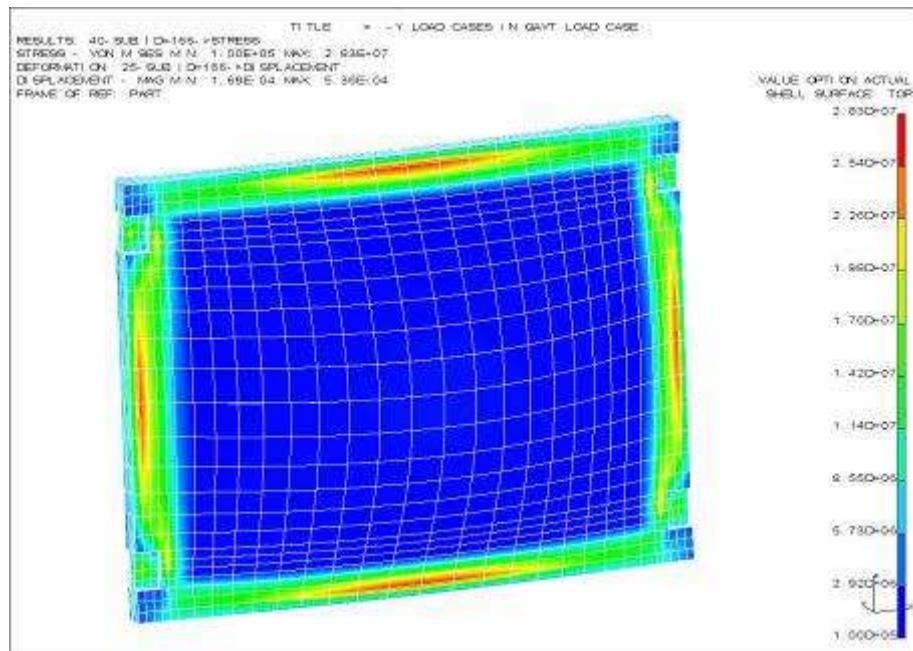


Figure 10-18: Maximum stress in LCD, 28.3 MPa occurred at edges of LCD housing in load case 66



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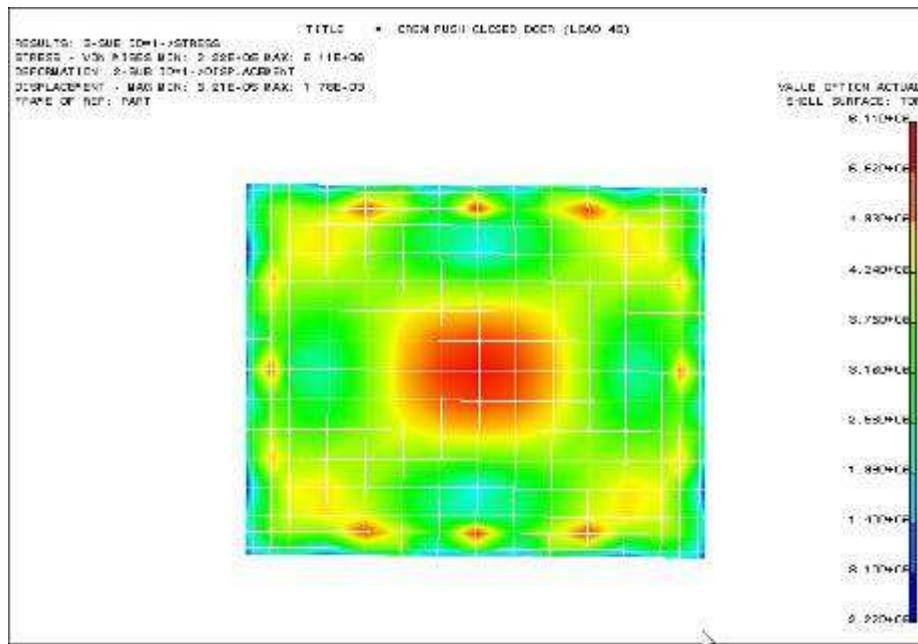


Figure 10-19: Maximum stress in Lexan layer, 6.11 MPa occurred at center of layer in load case 49

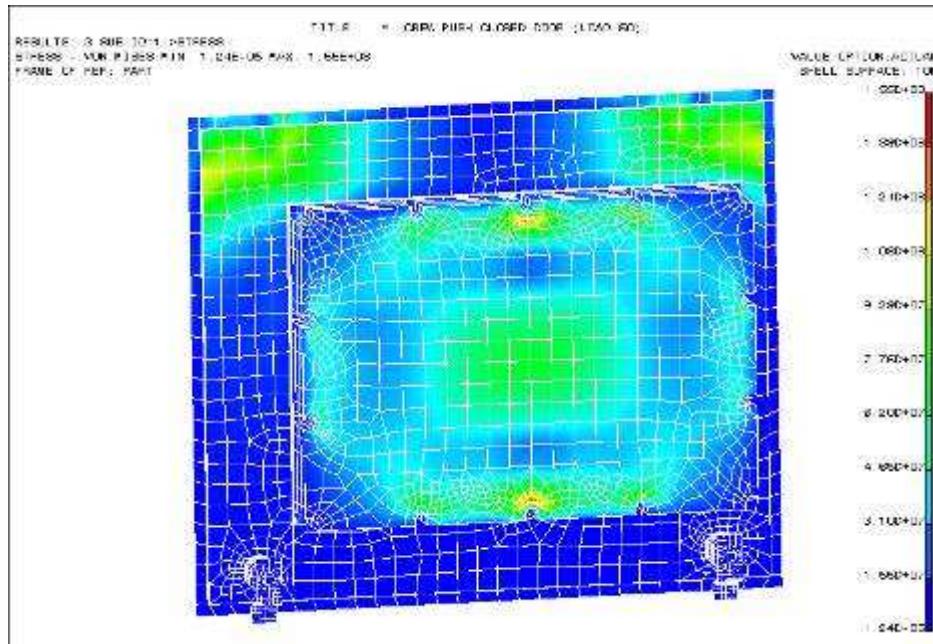


Figure 10-20: Maximum stress in door, 155 MPa occurred at center in LC 50.

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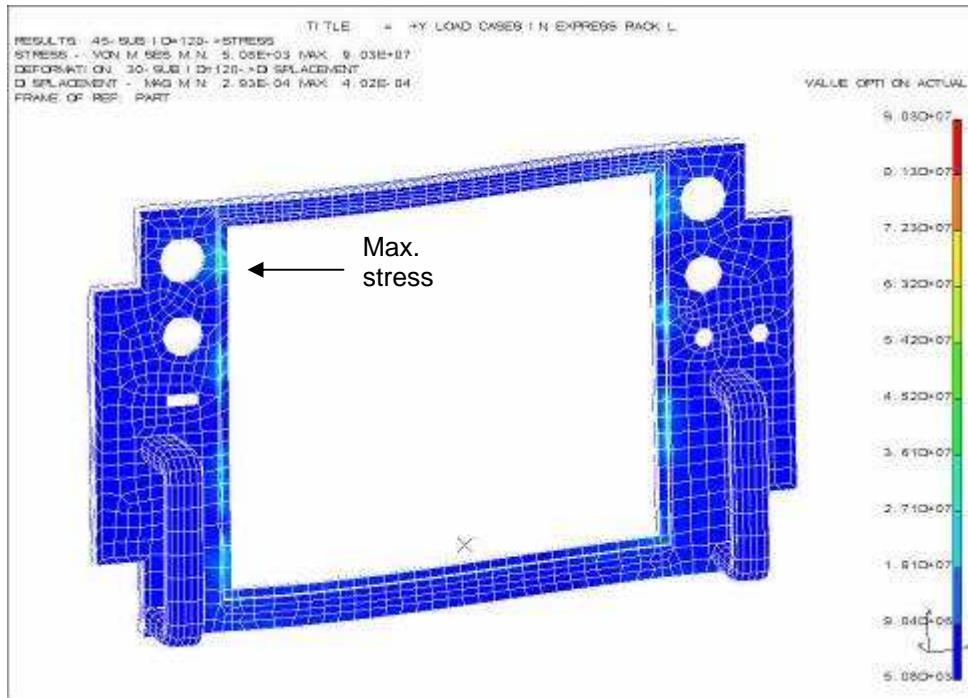


Figure 10-21: Maximum stress in front panel, 90.3 MPa occurred near top of the left side of door edge in LC 20

After structural analysis for all load cases we find the QAVT, Express lift-off, and crew-induced loads are the most serious cases. The emergency landing load case 25-30, the concentrated force on handle LC 31-48 and one g on one handle load case 51 can be covered by other critical cases in the Table 10-2: Maximum stress of each part. But some of load cases 31-48 and 51 are critical cases for joint analysis that will be discussed in next chapter. The pawl and housing of latch have verified in the previous Table and the shaft of latch will be checked in joint analysis. The LCD panel is assumed by 3mm acrylic resin layer that based on general product configuration. Thus the LCD panel will be verified by test not verified by structural analysis.

10.3 TAPER HOLE FOR THE CAPTIVE BOLT BEARING ANALYSIS

The taper hole for the captive bolt and retainer nut in the backplate is shown as the Figure 10-22. The flange with taper hole has enforced by the steel retainer after assembly. Besides the stress analysis for the flange in the backplate, in order to verify the nearby region of taper hole we also perform bearing, tension and shear out verification. We get the maximum force applied on the interface screw from the reaction force output from stress analysis (i.e. the maximum applied force for the bolt in the interface of ACOP and EXPRESS Rack), and conservatively use the smallest diameter of taper hole to calculate the MoS for bearing, use the minimum distance of hole-to-edge to calculated the MoS for tension and shear out. The related program is listed in ANNEX-3. The MoS of these verifications are listed in next Table.

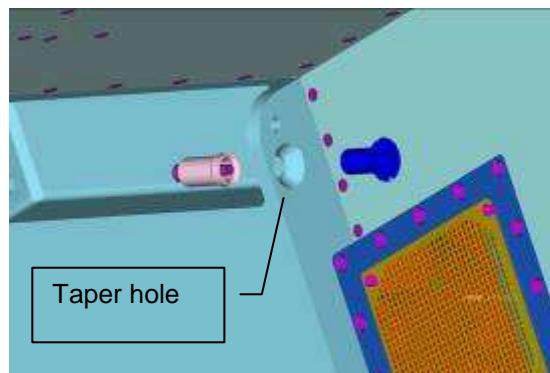


Figure 10-22: The taper hole for captive bolt and retainer nut

The Bearing, Tension and Shear Out Verification	
The material of lug	AL7075-T7351
The minimum diameter of hole	9.9mm
The minimum hole-to-edge distance	3.2mm
MoS_bry for bearing yield	15.486
MoS_bru for bearing ultimate	12.103
MoS_lugty for lug tension yield	6.5
MoS_lugtu for lug tension ultimate	4.592
MoS_lugsy for lug shear out yield	3.179
MoS_lugsu for lug shear out ultimate	2.125

Table 10-3: The MoS for bearing, tension and shear out of lug

The MoS for bearing, tension and shear out of lug are all positive and comply with the requirement.

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10.4 JOINT ANALYSIS

There are several types of bolt and related inserts including $\frac{1}{4}$ inch, #10, #8, #6, #4 etc. needed to comply with the positive margin of safety for critical load cases. This section gives a description of results of all joint analyses of the nominal configuration and the fail-safe configuration. In the following chapter all the bolts are divided in joint that include bolts with the same size and utilization.

The forces that are applied to the bolts come from the FE static analysis. For each joint all load cases are considered to find the maximum tension force (P), maximum shear force (V) and larger P combine with larger V that give the minimum MoS combined.

The analyses are performed using a template complied with the methodology and criteria defined in AD12, when applicable and the forces is not provided by the datasheet. A detail example of calculation step by step is listed in ANNEX 1

For each joint the following MOS are provided in Nominal configuration:

MOS	DESCRIPTION
MS1	Margin of Safety for joint separation
MS2	Margin of Safety for direct tension ultimate
MS3	Margin of Safety for direct tension yield
MS4	Margin of Safety for total tension ultimate
MS5	Margin of Safety for total tension yield
MS6	Margin of Safety for direct thread shear ultimate
MS7	Margin of Safety for total thread shear ultimate
MS8	Margin of Safety for shear ultimate
MS9	Margin of Safety for bending ultimate
MS10	Margin of Safety for combined shear, tension and bending ultimate

Table 10-4: MoS for joint in nominal configuration

For each joint the following MOS are provided in Fail Safe configuration:

MOS	DESCRIPTION
MS2	Margin of Safety for direct tension ultimate
MS4	Margin of Safety for total tension ultimate
MS6	Margin of Safety for direct thread shear ultimate
MS7	Margin of Safety for total thread shear ultimate
MS8	Margin of Safety for shear ultimate
MS10	Margin of Safety for combined shear, tension and bending ultimate

Table 10-5: MoS for joint in Fail Safe configuration

For the connection in which the AD12 is not applicable and the datasheet provided the allowable forces, the verification is based on this data.

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10.4.1 JOINTS DEFINITION

In the following table the definition of the joint is presented: for every joint the size of the bolt and the material are presented:

JOINT #	LOCATION DESCRIPTION	MATERIAL Ultimate	BOLT TYPE			REMARKS
			NAME	Diam. [mm]	Pitch	
JOINT 1	ACOP/EXPRESS Rack interface	A286 160ksi	CS5108C-4-5	6.35	28 p/in	AD12 (as NAS 1351N4) / Datasheet
JOINT 2	Chassis /Side walls	A286 160ksi	NAS1351N3	4.83	32 p/in	AD12
JOINT 3	Chassis fins/HDD frames, upper & lower adapters	A286 160ksi	NAS1352N04	2.84	40 p/in	AD12
JOINT 4a	Top plate/Side wall, backplate, front panel, chassis	A286 160ksi	SPS96395-94C	2.84	40 p/in	AD12
JOINT 4b	Bottom plate/Side wall, backplate, front panel, chassis	A286 160ksi	SPS96395-94C	2.84	40 p/in	AD12
JOINT 5	Air baffle/locker top, bottom plate and chassis	A286 160ksi	SPS96395-94C	2.84	40 p/in	AD12
JOINT 6	HDD connector frame/chassis	A286 160ksi	NAS1352N06	3.51	32 p/in	AD12
JOINT 7	Air shield/side walls	A286 160ksi	NAS1352N04	2.84	40 p/in	AD12
JOINT 8	Electronic board stiffeners, Backplane board stiffeners	A286 160ksi	NAS1352N04	2.84	40 p/in	AD12
JOINT 9	Fan frame/backplate, side walls	A286 160ksi	CA2261-06	3.51	32 p/in	Datasheet
JOINT 10a	Side walls/ backplate	A286 160ksi	SPS96395-94C	2.84	40 p/in	AD12
JOINT 10b	Side walls/ front panel	A286 160ksi	SPS96395-94C	2.84	40 p/in	AD12
JOINT 11	Fan/fan frame	A286 160ksi	SPS96395-94C	3.51	32 p/in	AD12
JOINT 12	Hinge/adapter, door, front panel	A286 160ksi	NAS1352N04	2.84	40 p/in	AD12
JOINT 13	LCD front cover plate/door adapter	A286 160ksi	SPS96395-94C	2.84	40 p/in	AD12
JOINT 14	ACOP-VI board/door adapter	A286 160ksi	NAS1352N04	2.84	40 p/in	AD12
JOINT 15	LCD mounted/door adapter	A286 160ksi	NAS1352N04	2.84	40 p/in	AD12
JOINT 16	LCD back-cover/door adapter	A286 160ksi	NAS 1352N04	2.84	40 p/in	AD12
JOINT 17	Small handle/door	A286 160ksi	NAS1352N04	2.84	40 p/in	AD12
JOINT 18	Large handle/front panel	A286 160ksi	NAS1351N3	4.83	32 p/in	AD12
JOINT 19	Latch	AISI 316 855MPa	E3-57	NA	NA	Datasheet

Table 10-6: The Classification of all Joints in ACOP



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The bolts in the interface of locker and Express rack are $\frac{1}{4}$ inch size for the configuration B defined in AD1 (section 3.4.3.6.2.1).

The joint ID's for the joint analysis are defined in the following figures.

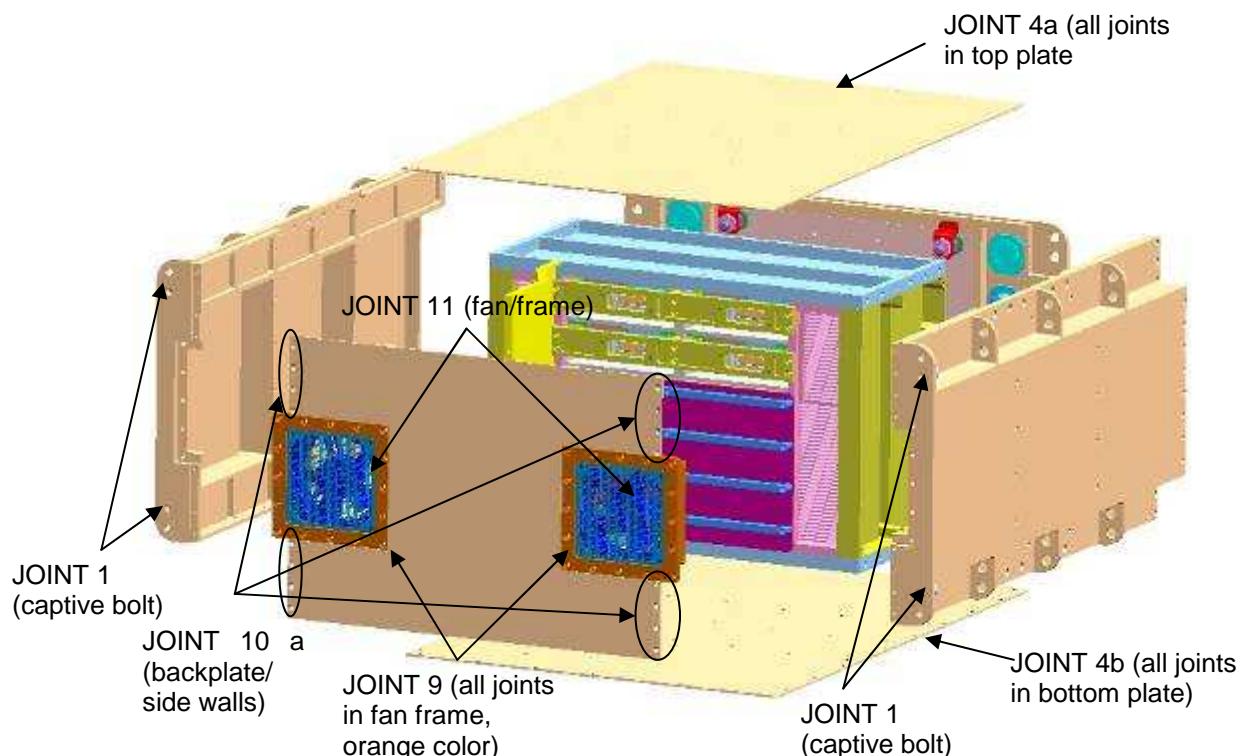


Figure 10-23: Joint ID in Nominal and Fail-Safe configuration



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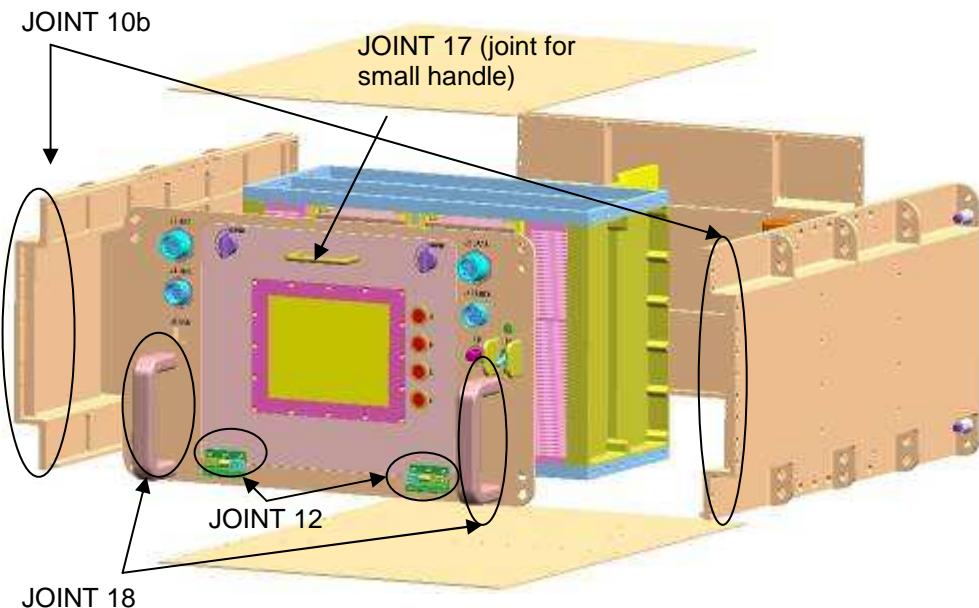


Figure 10-24: Joint ID in Nominal and Fail-Safe configuration

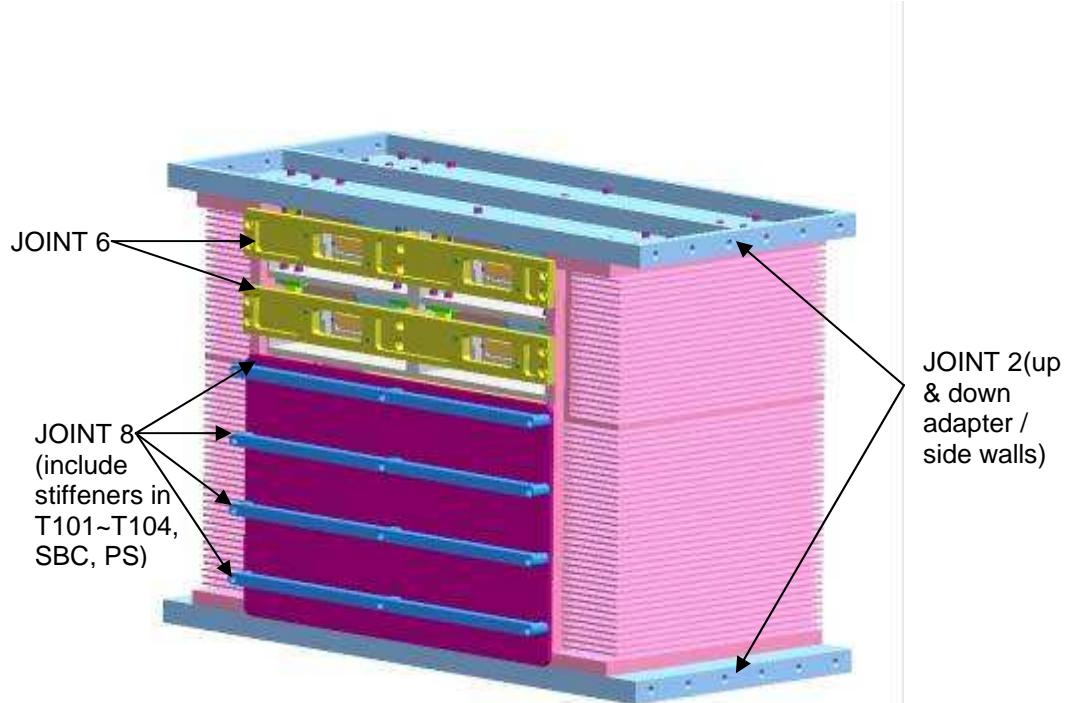


Figure 10-25: Joint ID in Nominal and Fail-Safe configuration



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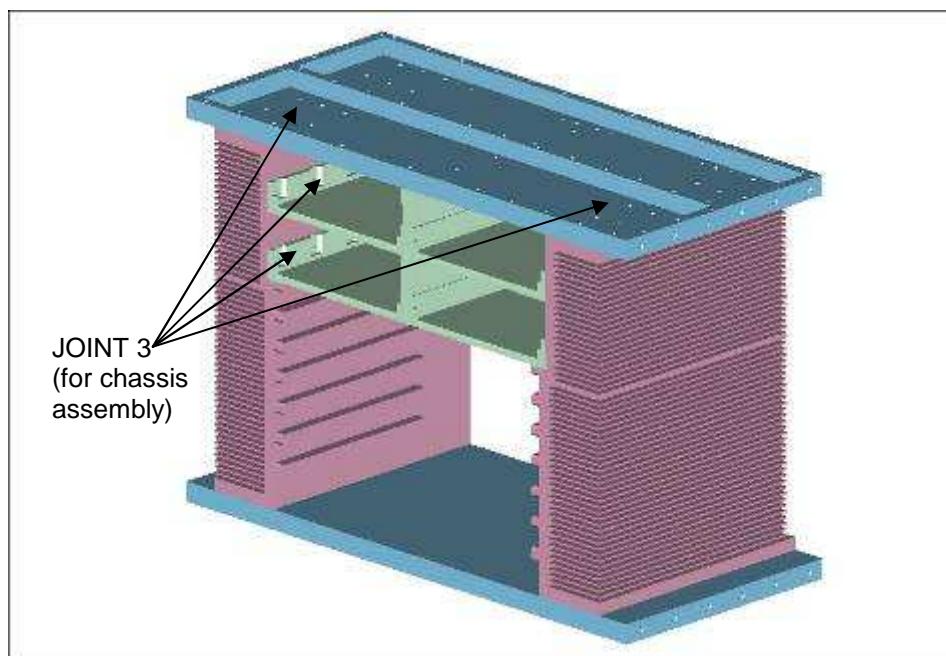


Figure 10-26: Joint ID in Nominal and Fail-Safe configuration

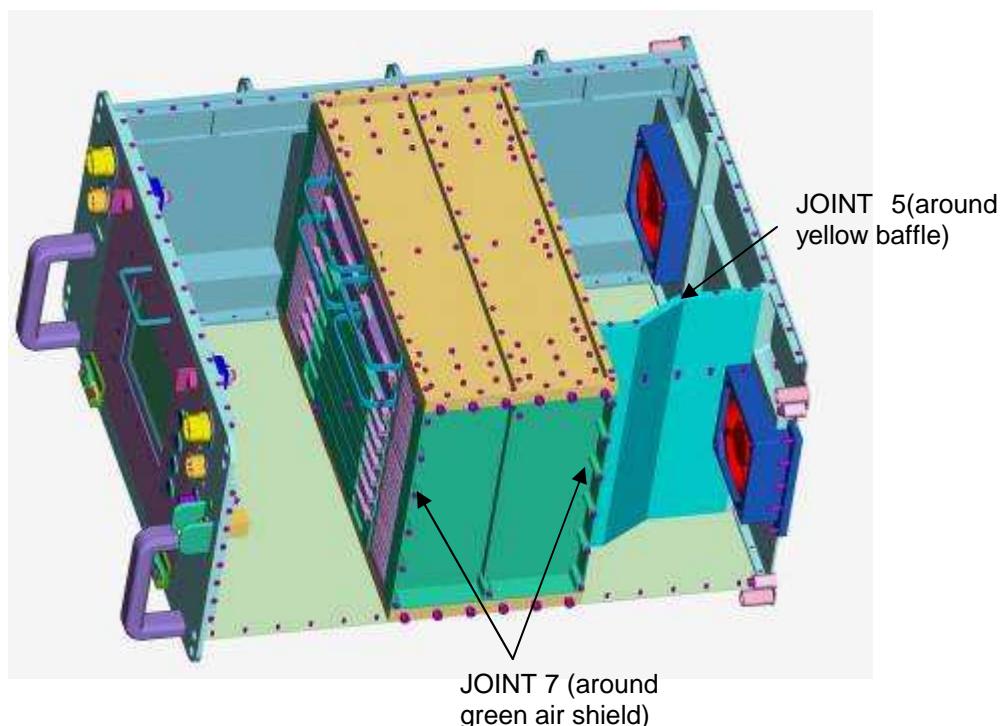


Figure 10-27: Joint ID in Nominal and Fail-Safe configuration



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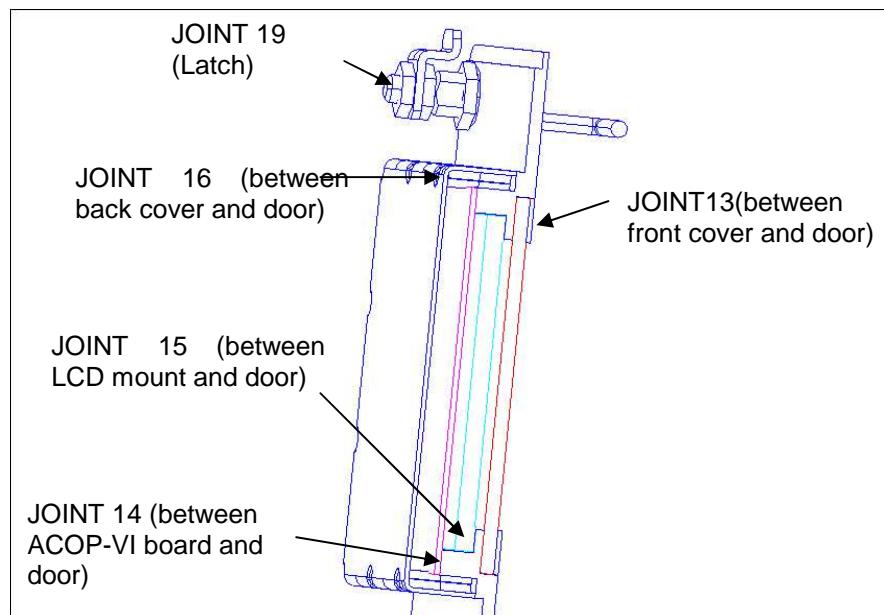


Figure 10-28: Joint ID in Nominal and Fail-Safe configuration

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The original design of the small handle (JOINT 17) with only one bolt for every side of the handle can not withstand the bending moment due to the crew-induced concentrated force in the Z_{fem} direction (load case 34 & 36). One bolt for each side should be added to the base of handle interface as shown in the following figures.

With respect to the preliminary design the new one replace NAS 1352N04 bolt with NAS 1352N08 bolt to enforce the joint.

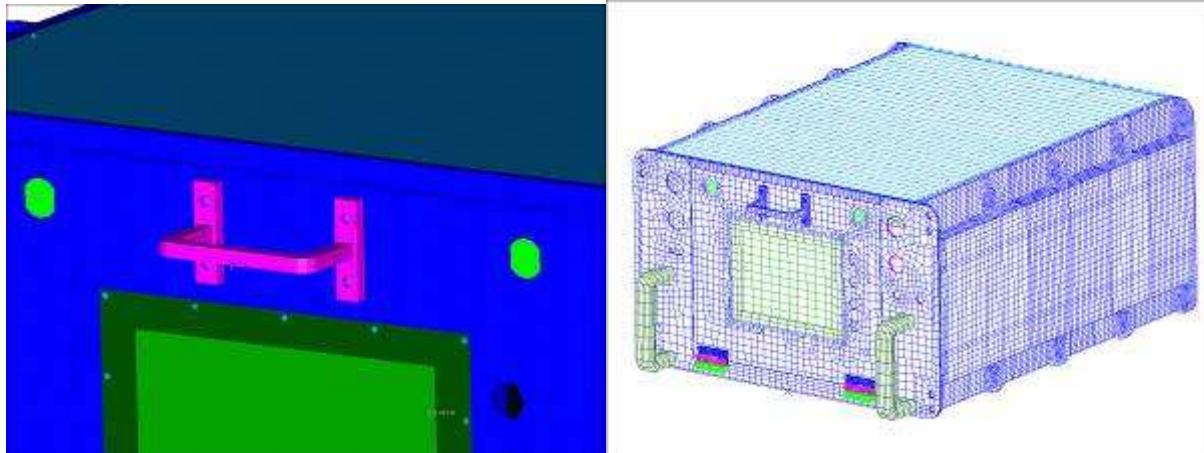


Figure 10-29: The modification of small Handle and its FE Model

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10.4.2 NOMINAL CONFIGURATION

The input data (applied forces, bolt information, material properties) for each joint analysis of nominal configuration and the output of Margins of safety (ten kinds of MoS's) from the calculation template are list in the next tables:

The common used properties of joint analysis are: (1) temperature range: -30 degree to 120 degree Fahrenheit defined in RD1 Table 5-1, (2) material strength derating factor due to temperature use 0.97, (3) the strength of insert use 160 Ksi, (4) thermal expansion coefficients refer to RD11.

JOINT	JOINT1	JOINT2	JOINT3	JOINT4a	JOINT4b
Bolt type	CS5108C-4-5	NAS1351N3	NAS1352N04	SPS96395-94C	SPS96395-94C
Insert type	MS51831CA-202 (1/4-28)	MS21209F1-15	MS21209-C0415	MS21209-C0410	MS21209-C0410
critical element no. JOINT-CR	N107420	E80009	E80167	E80356	E80403
load case no.	21	54	21	53	52
applied tensile force P (N)	5394.3	177.74	224.9	10.08	12.04
applied shear force V (N)	1639.6	429.09	291.13	643.07	800.25
bolt diameter D (mm)	6.35	4.826	2.845	2.845	2.845
bolt length L (mm)	17.45	12.7	9.53	6.35	6.35
threaded length Lt (mm)	12.7	12.7	9.53	6.35	6.35
numbers of thread Nt (1/in)	28	32	40	40	40
length of insert Lins (mm)	9.53	7.24	4.27	2.845	2.845
min diameter of insert Fmin (mm)	8.382	6.579	4.039	4.039	4.039
depth of recess lr (mm)	0.76	0.89	0.56	0.56	0.56
bolt head dia. dw (mm)	9.53	7.92	4.65	4.65	4.65
flange_1 thickness tf1 (mm)	6.3	3	1.6	2.0	2.0
flange_1 thickness tf2 (mm)	13	8	8.5	4.0	4.0
diameter of hole D_hole (mm)	6.8	5.3	3.2	3.2	3.2
bolt ultimate tensile Ftu_bolt (psi)	160000	160000	160000	160000	160000
bolt ultimate shear Fsu_bolt (psi)	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt
bolt yield tensile Fty_bolt (psi)	120000	120000	120000	120000	120000
max torque Tmax (N-m)	11.0	4.3	0.75	0.75	0.6
min torque Tmin (N-m)	10.0	3.87	0.675	0.675	0.54
Result of MoS					
MS1	0.004	13.551	2.311	73.113	45.296
MS2	0.963	31.506	6.597	168.494	140.902
MS3	1.356	38.008	8.116	202.393	169.283
MS4	0.355	0.681	0.625	0.696	1.093
MS5	0.08	0.266	0.238	0.273	0.571
MS6	1.57	29.601	7.757	196.86	164.652
MS7	0.774	0.583	0.873	0.98	1.442
MS8	2.576	6.358	2.073	0.391	0.118
MS9	10	10	10	10	10
MS10	0.32	0.671	0.523	0.139	0.021

Table 10-7: The joint analysis of each critical joint

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JOINT	JOINT5	JOINT6	JOINT7	JOINT8	JOINT9	JOINT10a
bolt type	SPS96395-94C	NAS1352N06	NAS1352N04	NAS1352N04	CA2261-06	SPS96395-94C
insert type	MS21209-C0410	MS21209-C0615	MS21209-C0410	MS21209-C0410	MS21209-C0615	MS21209-C0410
JOINT-CR	E80283	E80070	E80332	E80314	E80040	E80453
load case no.	18	55	6	58	2	2
P (N)	154.58	87.99	47.16	62.76	79.21	146.16
V (N)	189.53	246.98	23.61	362.14	697.06	74.3
D (mm)	2.845	3.51	2.845	2.845	3.51	2.845
L (mm)	6.35	9.53	6.35	9.53	12.3	6.35
Lt (mm)	6.35	9.53	6.35	9.53	12.3	6.35
Nt (1/in)	40	32	40	40	32	40
Lins (mm)	2.845	5.26	2.845	4.27	4.5	2.845
Fmin (mm)	4.039	4.902	4.039	4.039	5.7	4.039
Ir (mm)	0.56	0.56	0.56	0.56	0.53	0.56
dw (mm)	4.65	5.74	4.65	4.65	7.5	4.65
tf1 (mm)	2.0	2.5	3.0	2.0	2.5	2.3
tf2 (mm)	3.0	6.0	6.0	8.0	9.8	4.0
D_hole (mm)	3.2	3.7	3.2	3.2	3.7	3.2
Ftu_bolt (psi)	160000	160000	160000	160000	160000	160000
Fsu_bolt (psi)	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt
Fty_bolt (psi)	120000	120000	120000	120000	120000	120000
Tmax (N-m)	0.75	1.4	0.75	0.75	1.4	0.75
Tmin (N-m)	0.675	1.26	0.675	0.675	1.26	0.675
Result of MoS						
MS1	3.833	11.473	14.809	10.723	NA	4.11
MS2	10.053	28.286	35.228	26.223	NA	10.689
MS3	12.263	34.144	42.473	31.667	NA	13.027
MS4	0.654	0.667	0.688	0.675	NA	0.658
MS5	0.253	0.255	0.27	0.261	NA	0.255
MS6	11.902	49.862	41.291	46.696	NA	12.646
MS7	0.931	1.896	0.971	1.934	NA	0.935
MS8	3.72	4.434	36.887	1.47	NA	11.039
MS9	10	10	10	10	NA	10
MS10	0.62	0.644	0.688	0.483	NA	0.656

Table 10-8: The joint analysis of each critical joint

 CARLO GAVAZZI CARLO GAVAZZI SPACE SpA	<h1 style="text-align: center;">ACOP</h1>	Doc N°: ACP-RP-CGS-005
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JOINT	JOINT10b	JOINT11	JOINT12	JOINT13	JOIN14	JOINT15
bolt type	SPS96395-94C	SPS96395-96C	NAS1352N04	SPS96395-94C	NAS1352N04	NAS1352N04
insert type	MS21209-C0410	F-632-1	MS21209-C0415	MS21209-C0415	MS21209-C0410	MS21209-C0415
JOINT-CR	E80497	E80079	E80487	E80548	E80552	E80566
load case no.	1	71	66	49	50	60
P (N)	96.63	32.25	214.15	91.75	9.46	12.67
V (N)	54.79	165.87	47.95	225.12	121.84	9.04
D (mm)	2.845	3.51	2.845	2.845	2.845	2.845
L (mm)	6.35	9.53	6.35	11.11	6.35	9.53
Lt (mm)	6.35	9.53	6.35	11.11	6.35	9.53
Nt (1/in)	40	32	40	40	40	40
Lins (mm)	2.845	5.26	3.0	4.27	2.845	4.27
Fmin (mm)	4.039	4.902	4.039	4.039	4.039	4.039
Ir (mm)	0.56	0.56	0.56	0.56	0.56	0.56
dw (mm)	4.65	5.74	4.65	4.65	4.65	4.65
tf1 (mm)	2.95	3.0	3.0	6.6	1.6	3.0
tf2 (mm)	4.0	5.5	3.0	3.1	11.4	5.0
D_hole (mm)	3.2	3.7	3.2	3.2	3.2	3.2
Ftu_bolt (psi)	160000	160000	160000	160000	160000	160000
Fsu_bolt (psi)	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt
Fty_bolt (psi)	120000	120000	120000	120000	120000	120000
Tmax (N-m)	0.75	1.4	0.75	0.75	0.75	0.75
Tmin (N-m)	0.675	1.26	0.675	0.675	0.675	0.675
Result of MoS						
MS1	6.709	32.978	2.944	6.745	80.039	55.984
MS2	16.681	78.904	6.978	17.621	179.603	133.846
MS3	20.217	94.885	8.574	21.346	215.723	160.816
MS4	0.674	0.679	0.758	0.677	0.698	0.691
MS5	0.263	0.261	0.327	0.264	0.274	0.269
MS6	19.64	137.77	12.901	31.626	209.829	235.261
MS7	0.954	1.916	2.064	1.939	0.982	1.962
MS8	15.326	7.091	17.655	2.974	6.342	97.951
MS9	10	10	10	10	10	10
MS10	0.673	0.672	0.758	0.62	0.688	0.691

Table 10-9: The joint analysis of each critical joint

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JOINT	JOINT16	JOINT17	JOINT18	JOINT19
bolt type	NAS1352N04	NAS1352N08	NAS1351N3	E3-57
insert type	MS21209-C0410	MS21209-C0815	MS21209-F1-20	NA
JOINT-CR	E80573	E80595	E80007	NA
load case no.	49	34	44	NA
P (N)	129.0	157.45	498.22	109.87
V (N)	98.39	114.72	79.78	41.09
D (mm)	2.845	4.17	4.826	NA
L (mm)	9.53	9.53	22.23	NA
Lt (mm)	9.53	9.53	22.23	NA
Nt (1/in)	40	32	32	NA
Lins (mm)	4.27	4.53	9.65	NA
Fmin (mm)	4.039	5.7	6.579	NA
lr (mm)	0.56	0.53	0.89	NA
dw (mm)	4.65	7.5	7.92	NA
tf1 (mm)	4.6	5.0	13.	NA
tf2 (mm)	7.5	4.5	20.	NA
D_hole (mm)	3.2	4.7	5.3	NA
Ftu_bolt (psi)	160000	160000	160000	NA
Fsu_bolt (psi)	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	NA
Fty_bolt (psi)	120000	120000	120000	NA
Tmax (N-m)	0.75	2.6	4.3	NA
Tmin (N-m)	0.675	2.34	3.87	NA
Result of MoS				
MS1	4.552	0.953	3.843	NA
MS2	12.244	24.519	10.597	NA
MS3	14.893	29.523	12.916	NA
MS4	0.664	0.671	0.665	NA
MS5	0.257	0.258	0.258	NA
MS6	22.205	27.464	21.117	NA
MS7	1.916	0.864	2.175	NA
MS8	8.092	17.77	38.576	NA
MS9	10	10	10	NA
MS10	0.659	0.691	0.665	NA

Table 10-10: The joint analysis of each critical joint

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10.4.2.1 JOINT 1 ADDITIONAL ANALYSIS

The MoS of JOINT 1 verification in the TABLE 10-7 is based on properties of bolt type NAS1351N4. The minimum MoS is 0.004 (joint separation). In addition there are evaluations will perform on the allowable force of JOINT 1 defined in product data sheet and RD 9.

The captive screw used for JOINT1 adopts CS5108C-4-5 (by F.I.T. INC) whose allowable ultimate forces listed in TABLE 10-11. And allowable of insert MS51831CA-202 for JOINT1 had defined in RD 9 Table3-II.

Item	Ultimate force allowable	
	Tensile (lbf)	Shear (lbf)
CS5108 captive bolt	5900	3600
MS51831CA-202 insert	8900	19600

Table 10-11: allowable of Joint 1

Since the allowable of insert are greater than captive screw, we use the allowable of CS5108 to verify joint safety. A program listed as ANNEX-2 is used for MoS calculation, and the summary of MoS is list in the following table

MoS	Value
Direct Tension Ultimate	MS2
Direct Tension Yield	MS3
Total Tension Ultimate	MS4
Total Tension Yield	MS5
Shear Ultimate	MS8
Combined shear, tension ultimate	MS10

Table 10-12: MOS of Joint1 based on product allowable

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10.4.2.2 JOINT 9 ANALYSIS

The Joint 9 uses the captive bolt CA2261 dash 06 (0.138[in] with a pitch of 32[1/in]). The datasheet provide the minimum calculated allowable of:

Axial	Shear
4715 N	2846 N

Table 10-13: Allowable of Captive screw (from datasheet)

These values are used to verify the forces that come from the static analysis:

Axial	Shear
79.21 N	697.06 N

Table 10-14: Applied forces on the Joint 9

$$R_{AX} = \frac{Axial_{app} \times FS_u}{Axial_{all}} = \frac{79.21 \times 2}{4715} = 0.033$$

$$R_{SH} = \frac{Shear_{app} \times FS_u}{Shear_{all}} = \frac{697.06 \times 2}{2846} = 0.49$$

$$R = R_{AX}^2 + R_{SH}^2 = 0.24$$

$$MoS_u = \frac{1}{R} - 1 = 3.16$$

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10.4.2.3 JOINT 19 ANALYSIS

The approach for the bolt analysis (shown in the ANNEX 1) is based on the assumption of two flanges fastened by two screws that can not suit for joint analysis of latch shaft and nut. The joint analysis for latch will list as following steps with the ultimate allowable force in the producer (SouthCo Inc.) data sheet shown in the following Table.

Part item	Ultimate allowable
E3-57 compression latch	780 N

Table 10-15: Allowable of latch

These values are used to verify the forces that come from the static analysis:

Axial	Shear
109.87 N	41.09 N

Table 10-16: Applied forces on the Joint 19

We use the greater force (tension) to check the safety.

$$MoS_u = \frac{P_u}{P \times FS_u} - 1 = \frac{780.}{109.87 \times 2.0} - 1 = 2.55$$

It is positive and compliant with requirement.

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10.4.3 FAIL-SAFE CONFIGURATION

The fail-safe configuration assumes the critical bolt failed and took off (see chapter 10.4.3.1), and the MoS of the others bolts have to maintain positive values after the applied load re-distribution. The factor of safety for fail-safe analysis is 1.0 for ultimate (see Table 8-1).

The re-distributed applied loads and MOS of Fail-Safe analysis are list in the Chapter 10.4.3.5 other input data are the same as in the nominal configuration.

Additional verifications (modal and strength) are performed for the failure of the joint 1 and joint 19 (see chapter 10.4.2.1 and 10.4.2.3)

10.4.3.1 FAILED BOLT DEFINITION

The following figures show the critical bolt location in each JOINT group. The “JOINTxx-CR” means the critical bolt in “JOINTxx” for nominal configuration, and the “JOINTxx-FS” for fail-safe configuration.

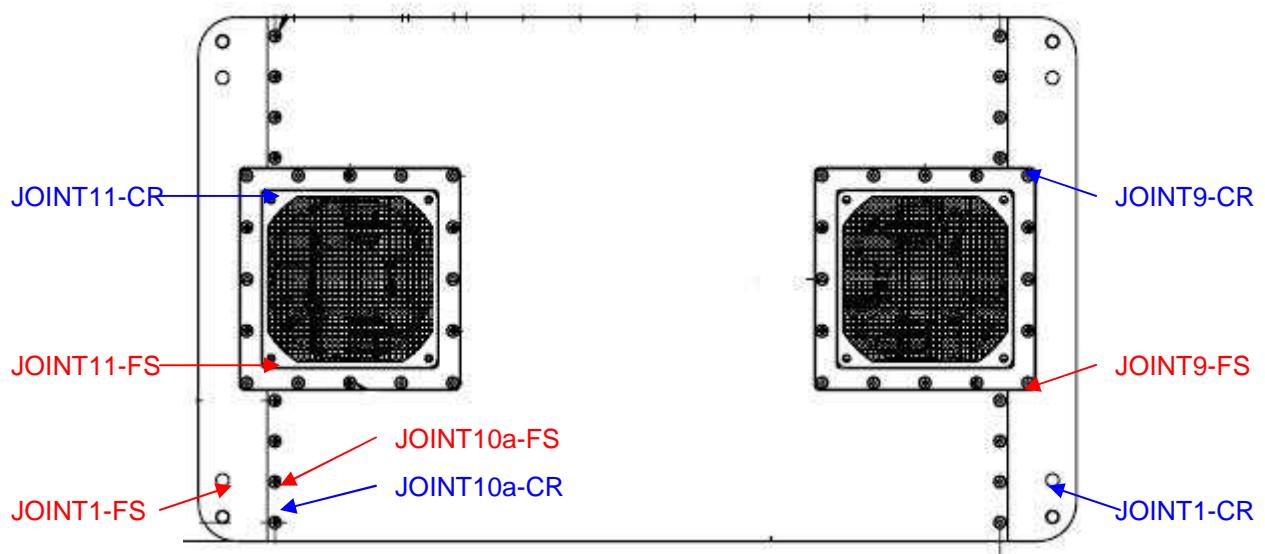


Figure 10-30: Critical Joints in nominal and Fail-Safe configuration



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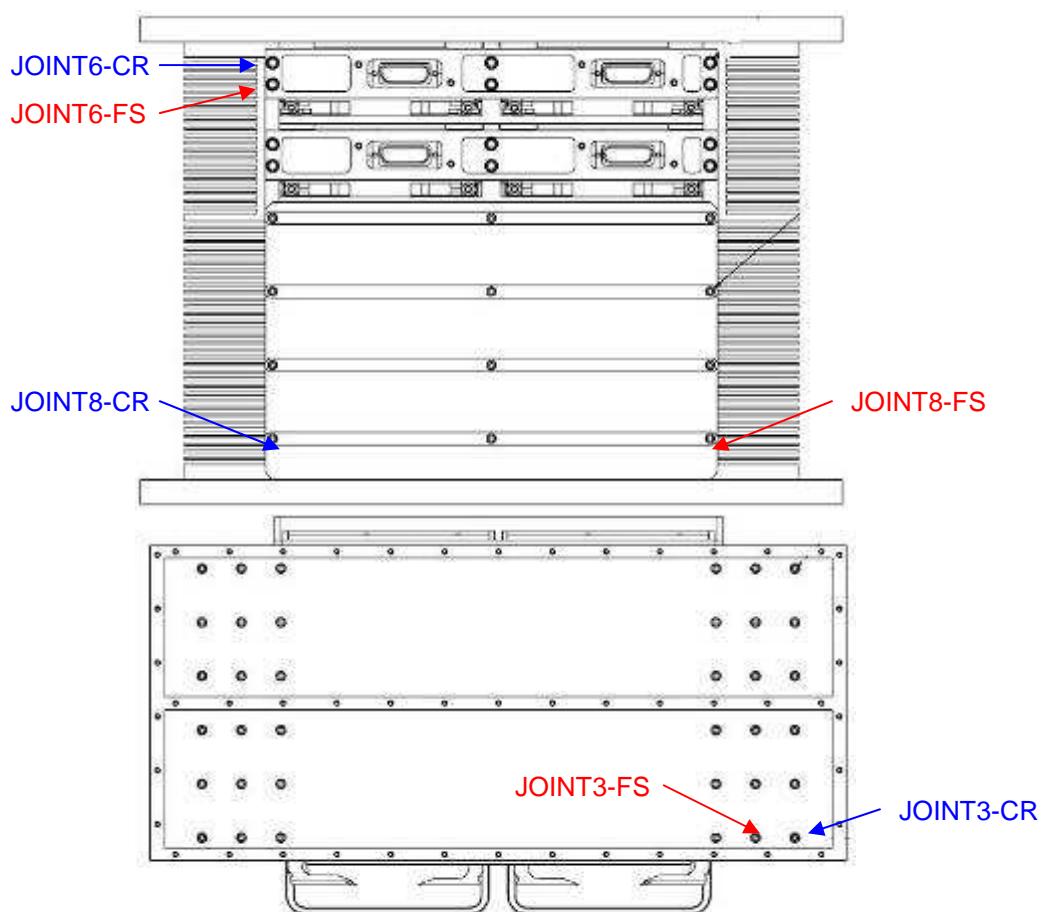


Figure 10-31: Critical Joints in nominal and Fail-Safe configuration



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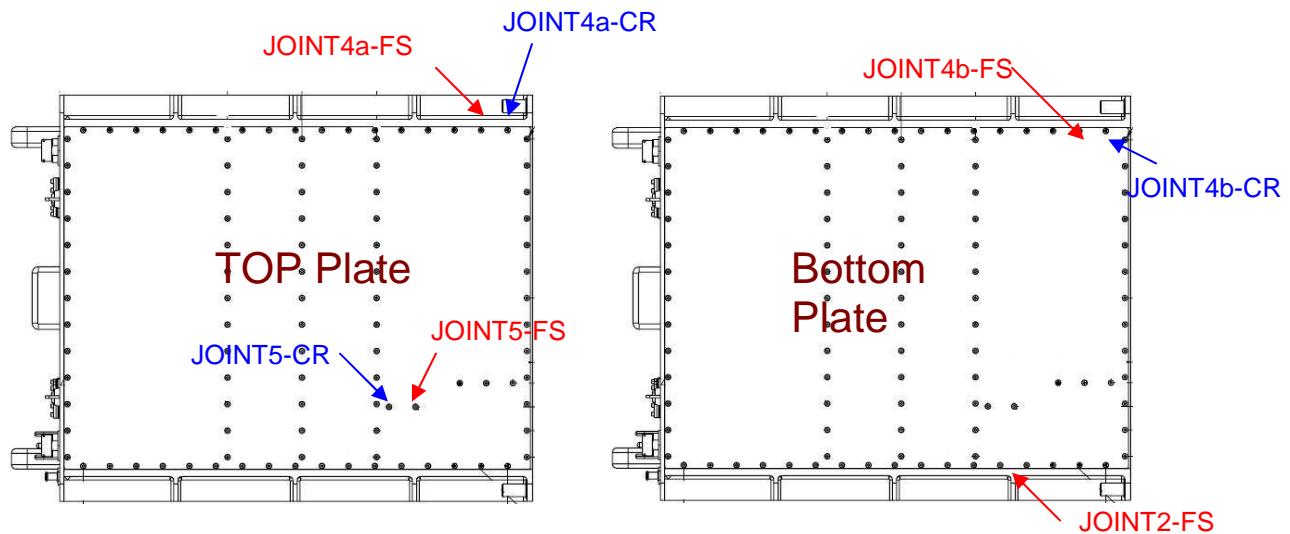


Figure 10-32: Critical Joints in nominal and Fail-Safe configuration

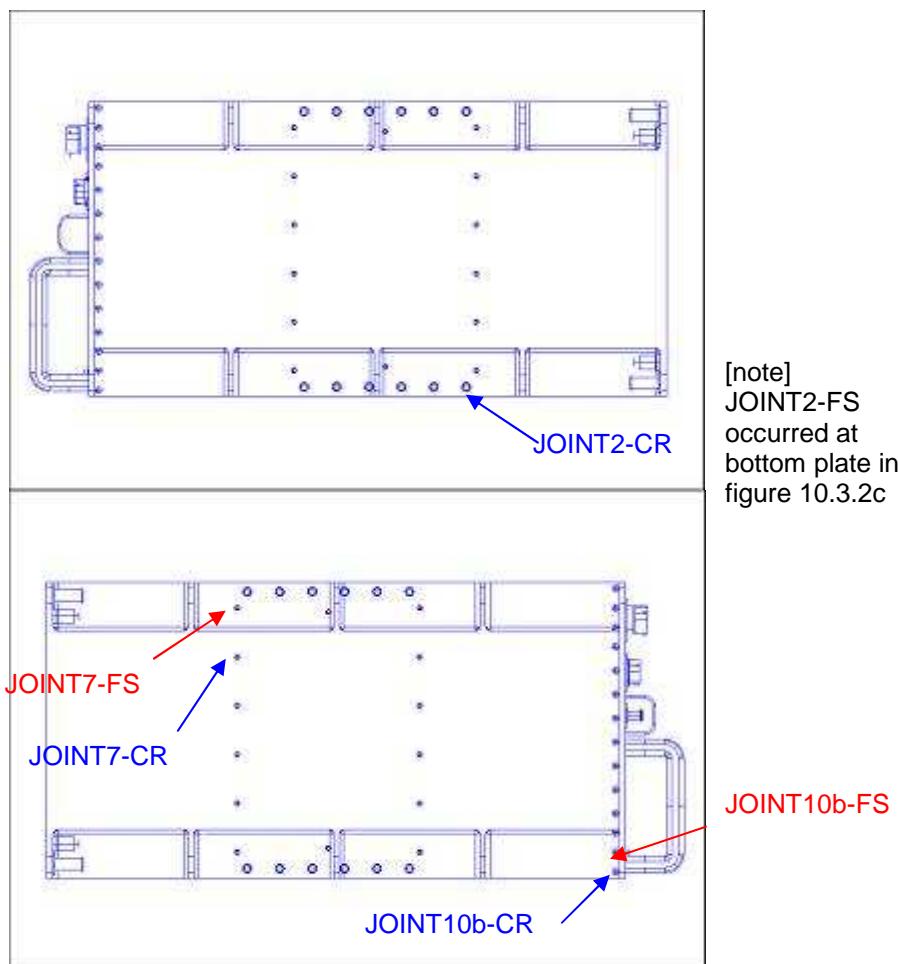


Figure 10-33: Critical Joints in nominal and Fail-Safe configuration



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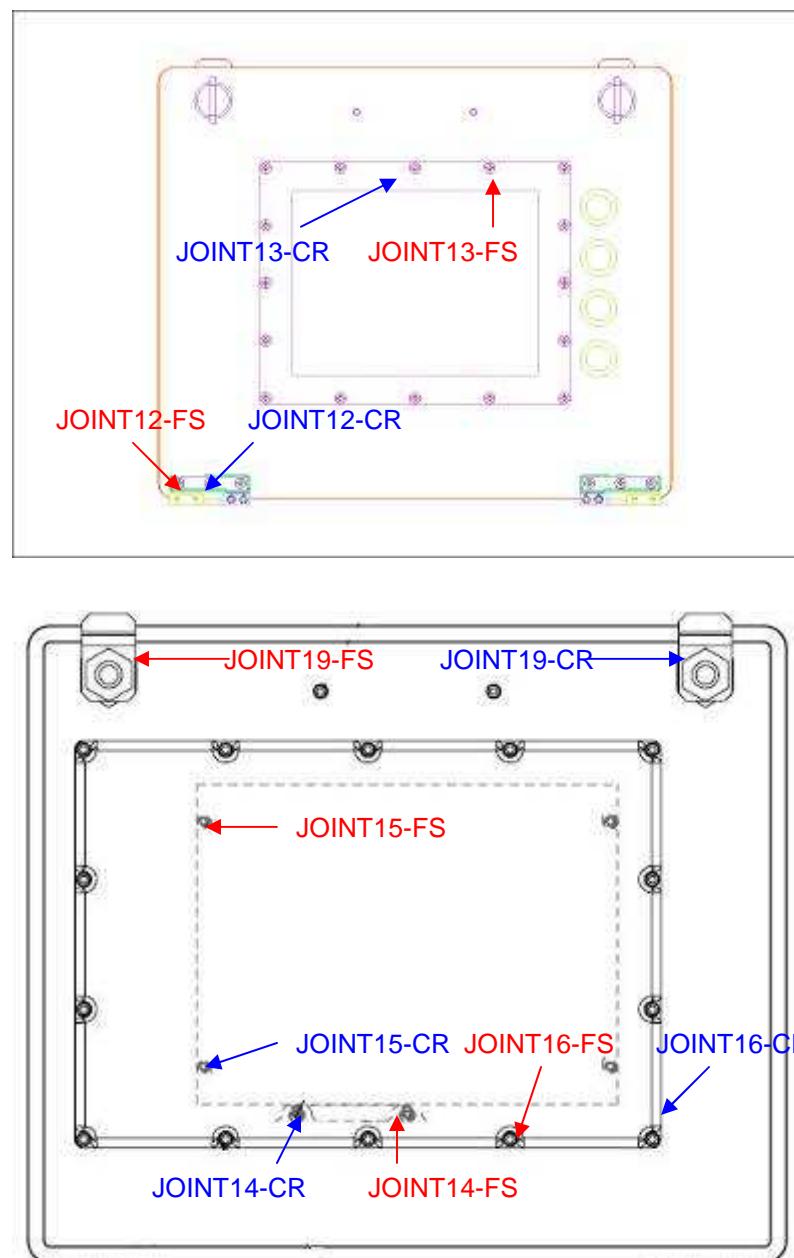


Figure 10-34: Critical Joints in nominal and Fail-Safe configuration



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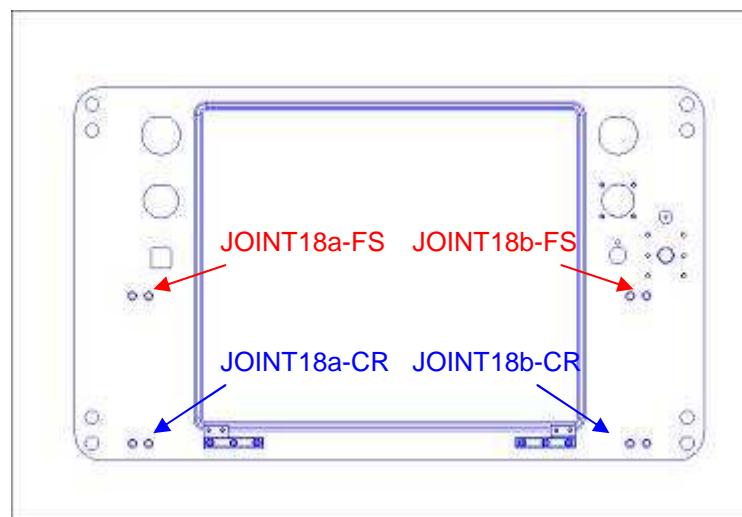


Figure 10-35: Critical Joints in nominal and Fail-Safe configuration

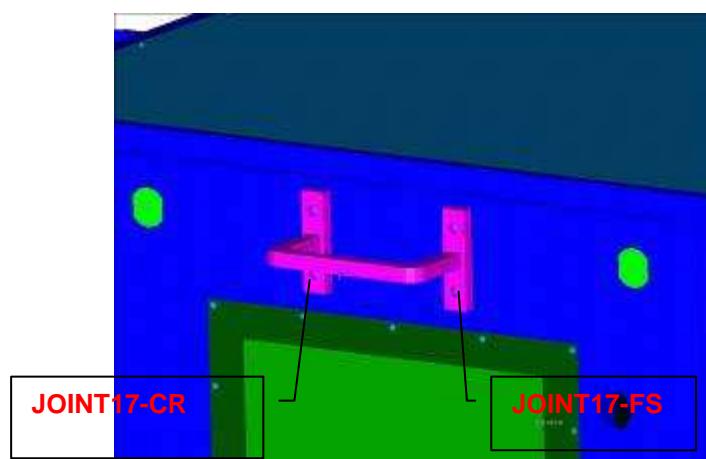


Figure 10-36: Critical Joints in nominal and Fail-Safe configuration

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10.4.3.2 JOINT 1 FS ADDITIONAL ANALYSES

All the Joints, except the Joint 1 and Joint 19, are used for component assembly with many redundant bolts; the removed critical bolt in each JOINT has just a little influence on mode frequency changes for the fail-safe configuration. We can use the same critical loads in the nominal configuration for fail-safe analysis. And the bolts in the handle use the crew-induced pull force as applied load without any relationship about natural frequency changes. We can also use the same concentrated force as the load for fail-safe analysis.

The JOINT1 in the backplate is the main mounting region for locker. There are some influences on the natural frequency for the fail-safe configuration. The modal analysis, load dimensioning and static analysis for the fail-safe configuration of JOINT1 are performed again.

The natural frequencies and effective masses of the fail-safe configuration of JOINT1 are list as follows.

MODE	FREQUENCY (HZ)	X FRACTION	X EFFMASS	Y FRACTION	Y EFFMASS	Z FRACTION	Z EFFMASS
1	87.14	8.83%	2.417	3.37%	0.922	62.24%	17.028
2	155.50	60.57%	18.987			10.86%	19.998
3	157.39	10.81%	21.944	1.80%	1.415	0.80%	20.217
10	213.78			5.93%	3.039	0.67%	20.401
11	219.90					0.36%	20.500
16	228.14			3.15%	3.900		
17	230.38					0.43%	20.617
19	241.52					0.69%	20.804
25	267.07			6.58%	5.700	2.34%	21.444
26	274.65			1.91%	6.223	0.77%	21.655
29	308.64			2.73%	6.969	0.23%	21.718
38	336.21			3.11%	7.819		
42	366.30			17.40%	12.580	0.26%	21.790
48	394.08			5.94%	14.205		
49	402.16			14.38%	18.138	0.41%	21.902
50	405.19			3.10%	18.987		
52	409.52			2.83%	19.761		
53	424.88			2.88%	20.547		
61	457.72			2.55%	21.246		
76	489.55			2.80%	22.013		
	SUM	80.21%	21.944	80.46%	22.013	80.06%	21.902

Table 10-17: The effective mass of ACOP with the failure of the Joint1



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By the same methodology of load dimensioning described in chapter 7 the critical load factors for the fail-safe configuration of JOINT 1 become to (7.7, -11.6, 17.224) g and are named load case FS1. It is less than the critical load for the nominal configuration (7.7, -11.6, 22.01) g in the Z_{fem} -axis. The results of the modal analysis and the static analysis for the new load factors are shown as bellows.

The first mode frequency 87.73 Hz is still greater than 35 Hz defined in the AD1 requirement.

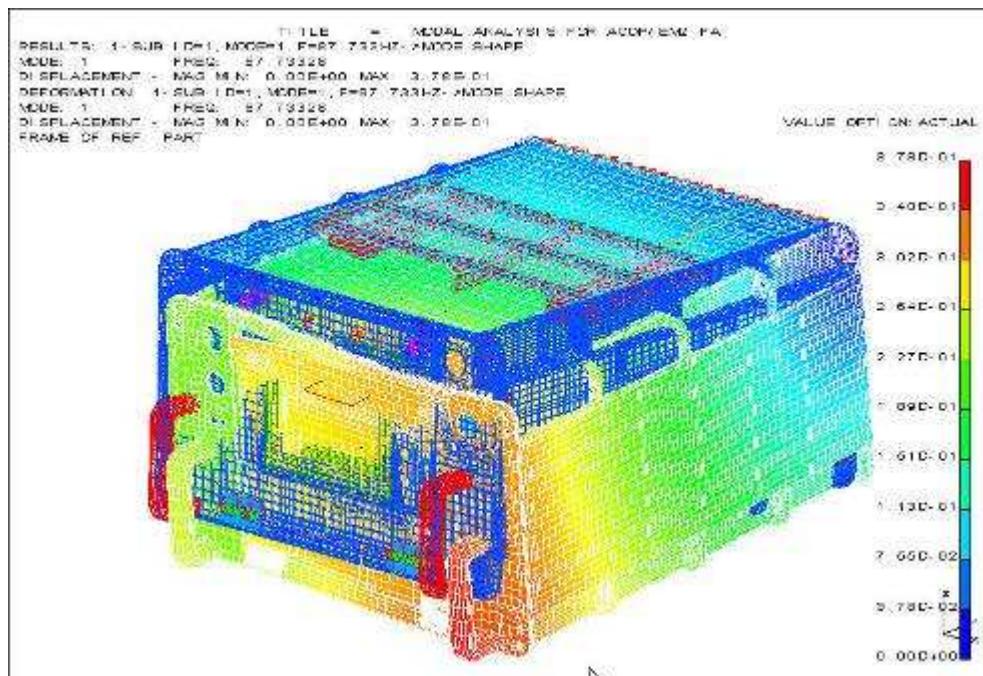


Figure 10-37: First mode shape of Fail-Safe configuration of Joint1. (global mode of locker)

The maximum stress of JOINT1 for the fail-safe configuration is 290Mpa, and the MoS of stress equals to 0.568 with the factor of safety for ultimate 1.0. It complies with the requirement of the positive MoS.

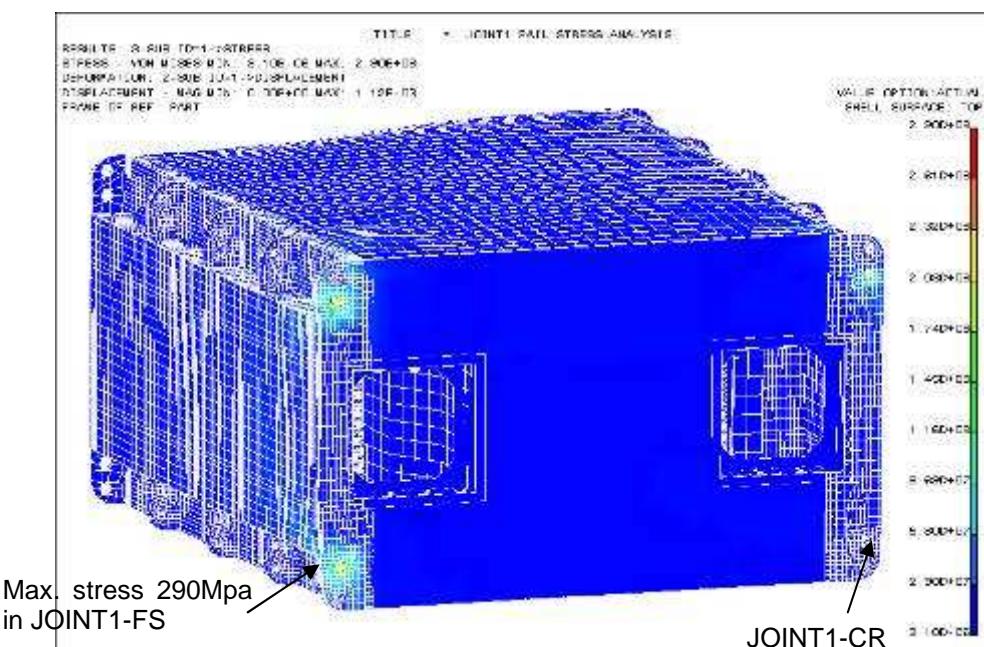


Figure 10-38: Maximum stress of Fail-Safe configuration of Joint1.

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Besides the stress analysis for the flange in the backplate, we also perform bearing, tension and shear out analysis to verify the nearby region of taper hole in the backplate for the fail-safe configuration. They are all positive and comply with the requirement.

The Bearing, Tension and Shear Out Verification	
Fail-safety configuration for JOINT1	
MoS_bru for bearing ultimate	19.391
MoS_lugtu for lug tension ultimate	7.703
MoS_lugsu for lug shear out ultimate	3.863

Table 10-18: MOS for bearing, tension and shear out verification for Fail-Safe configuration

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10.4.3.3 JOINT 19 FS ADDITIONAL ANALYSES

The JOINT 19 in the door is the main mounting shaft for latch. There are some influences on the natural frequency of ACOP crate for the fail-safe configuration. The modal analysis, load dimensioning and static analysis for the fail-safe configuration of JOINT 19 are performed again.

The natural frequencies and effective masses of the fail-safe configuration of JOINT19 are list as follows.

MODE	Frequency (Hz)	X Fraction	X Eff mass	Y Fraction	Y Eff mass	Z Fraction	Z Eff mass
1	104.11			4.51%	1.23	0.15%	0.04
2	128.79					76.21%	20.85
5	172.17	80.97%	80.97%				
6	185.13					0.22%	0.06
10	195.47					0.65%	0.18
11	219.71					0.15%	0.04
17	230.47					0.56%	0.15
18	233.12					0.22%	0.06
24	253.35			5.31%	1.45		
25	257.19					0.31%	0.09
26	273.84			4.61%	1.26		
27	274.32					1.06%	0.29
38	330.12					0.18%	0.05
40	337.83			1.23%	0.34		
49	394.41					0.43%	0.12
50	407.13			1.91%	0.52		
53	420.53			5.96%	1.63		
57	433.16			5.61%	1.53		
58	436.21			39.08%	10.69		
61	456.57			1.34%	0.37		
62	460.21			8.81%	2.41		
65	472.12			2.59%	0.71		
	SUM	80.97%	22.15	80.95%	22.15	80.16%	21.93

Table 10-19: Effective mass of Joint19 in Fail-Safe configuration

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By the same methodology of load dimensioning described in chapter 7 the critical load case 65 (QAVT load) for the fail-safe configuration of JOINT 19 become to (2.41, -24.11, -2.41) g and are named load case FS 2. It is less than the critical load for the nominal configuration (2.47, -24.71, -2.47) g in the Y_{fem} -axis. Since initial load for fail-safe configuration is less than nominal configuration, all ACOP structure response except front door components will be less than that in nominal configuration. The results of the modal analysis and the static analysis for the new load factors are shown as bellows.

The first mode frequency 104.1 Hz is still greater than 35 Hz defined in the AD1 requirement.

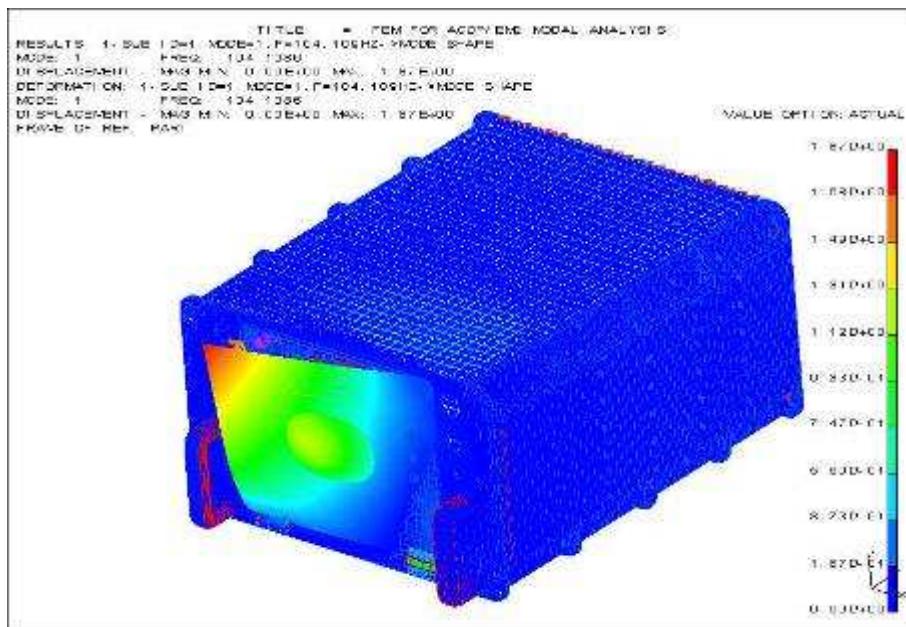


Figure 10-39: First mode shape for Fail-Safe configuration of joint 19. (the local mode of door)

The maximum stress of JOINT 19 for the fail-safe configuration is 105Mpa for left side hinge, and 77.8Mpa for the pawl of right side latch. The MoS of stress equals to 6.90 for hinge, 5.276 for latch pawl with the factor of safety for ultimate 1.0. They all comply with the requirement of the positive MoS.

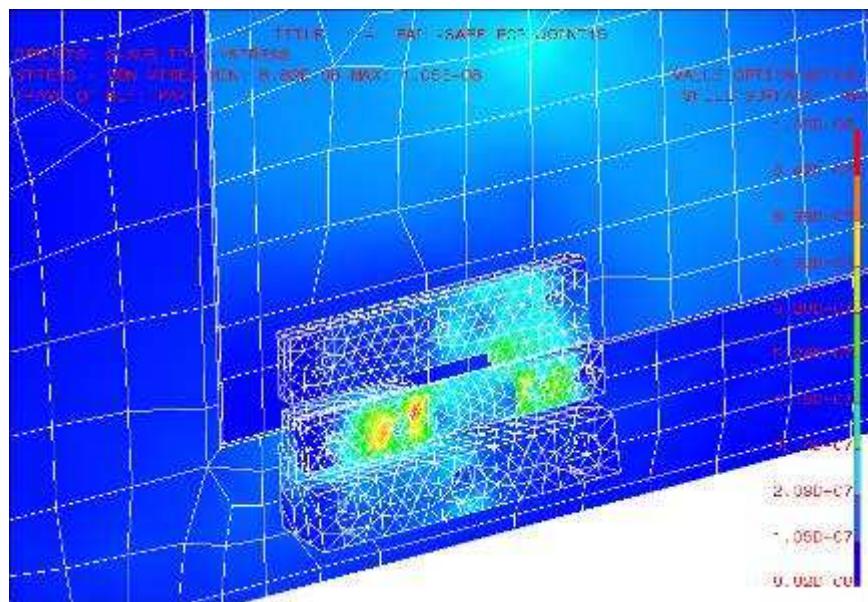


Figure 10-40: Maximum stress of hinge in Fail-Safe configuration of Joint 19.

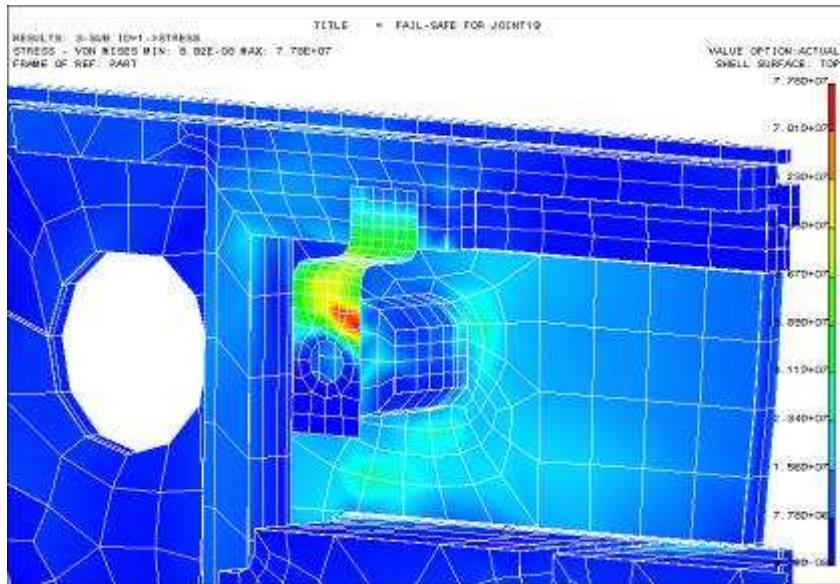


Figure 10-41: Maximum stress of latch in Fail-Safe configuration of joint 19.

The response for fail-safe analysis become to tension force 403.07 newtons, shear force 28.536 newtons in hinge joint. They are used for MoS_FS calculation with factor of safe 1.0 for ultimate. The joint for hinge in the load FS 2 is verified by the program (list in ANNEX-1) and the results are list in Table 10-25. The minimum MoS of the joint of hinge for JOINT 19 failure is 0.646 for combined ultimate. It is compliant with the positive margin of safety requirement.

10.4.3.4 JOINT 19 FS ANALYSIS

The joint analysis for latch will list as following steps with the ultimate allowable force in the producer (SouthCo Inc.) data sheet shown in the following Table.

Part item	Ultimate allowable
E3-57 compression latch	780 N

Table 10-20: Allowable of latch

These values are used to verify the forces that come from the static analysis:

Axial	Shear
215.87 N	33.348 N

Table 10-21: Applied forces on the Joint 19

We use the greater force (tension) to check the safety.

$$MoS_u = \frac{P_u}{P \times FS_u} - 1 = \frac{780}{215.87 \times 1.0} - 1 = 2.613$$

It is positive and compliant with requirement.

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10.4.3.5 FAIL SAFE ANALYSIS

The JOINT1-FS response become to axial force 7595.78 N, shear force 2107.17 N and put into The TABLE 10-22 for MoS_FS calculation with factor of safe 1.0 for ultimate. Other new joint forces of JOINT2~18b for the fail-safe configuration are list in TABLE 10-22, TABLE 10-23, TABLE 10-24, and TABLE 10-25

JOINT	JOINT1	JOINT2	JOINT3	JOINT4a	JOINT4b
bolt type	CS5108C-4-5	NAS1351N3	NAS1352N04	SPS96395-94C	SPS96395-94C
insert type	MS51831CA-202 (1/4-28)	MS21209F1-15	MS21209-C0415	MS21209-C0410	MS21209-C0410
Critical element no. JOINT-FS	N107418	E80418	E80166	E80358	E80407
load case no.	FS1	54	21	53	52
applied tensile force P (N)	7595.78	9.52	199.84	46.39	60.04
applied shear force V (N)	2107.17	346.08	212.41	456.36	603.88
bolt diameter D (mm)	6.35	4.826	2.845	2.845	2.845
bolt length L (mm)	17.45	12.7	9.53	6.35	6.35
threaded length Lt (mm)	12.7	12.7	9.53	6.35	6.35
numbers of thread Nt (1/in)	28	32	40	40	40
length of insert Lins (mm)	9.53	7.24	4.27	2.845	2.845
min diameter of insert Fmin (mm)	8.382	6.579	4.039	4.039	4.039
depth of recess lr (mm)	0.76	0.89	0.56	0.56	0.56
bolt head dia. dw (mm)	9.53	7.92	4.65	4.65	4.65
flange_1 thickness tf1 (mm)	6.3	3	1.6	2.0	2.0
flange_1 thickness tf2 (mm)	13	8	8.5	4.0	4.0
diameter of hole D_hole (mm)	6.8	5.3	3.2	3.2	3.2
bolt ultimate tensile Ftu_bolt (psi)	160000	160000	160000	160000	160000
bolt ultimate shear Fsu_bolt (psi)	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt
max torque Tmax (N-m)	11.0	4.3	0.75	0.75	0.6
min torque Tmin (N-m)	10.0	3.87	0.675	0.675	0.54
Result of MoS					
MS2	1.788	357.93	16.099	72.658	55.912
MS4	0.421	0.698	0.662	0.692	0.69
MS6	2.651	41.8	28.958	84.986	65.437
MS7	0.861	0.982	1.912	0.975	0.973
MS8	4.565	4.169	7.423	2.92	1.963
MS10	0.41	0.669	0.656	0.63	0.561

Table 10-22: Fail-Safe analysis of each critical Joint

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JOINT	JOINT5	JOINT6	JOINT7	JOINT8	JOINT9	JOINT10a
bolt type	SPS96395-94C	NAS1352N06	NAS1352N04	NAS1352N04	CA2261-06	SPS96395-94C
insert type	MS21209-C0410	MS21209-C0615	MS21209-C0410	MS21209-C0410	MS21209-C0615	MS21209-C0410
JOINT-FS	E80282	E80069	E80336	E80315	E80040	E80454
load case no.	18	55	6	58	2	2
P (N)	37.43	0.33	5.43	73.95	43.15	29.11
V (N)	172.83	19.45	30.52	402.86	233.39	377.5
D (mm)	2.845	3.51	2.845	2.845	3.51	2.845
L (mm)	6.35	9.53	6.35	9.53	12.3	6.35
Lt (mm)	6.35	9.53	6.35	9.53	12.3	6.35
Nt (1/in)	40	32	40	40	32	40
Lins (mm)	2.845	5.26	2.845	4.27	4.5	2.845
Fmin (mm)	4.039	4.902	4.039	4.039	5.7	4.039
lr (mm)	0.56	0.56	0.56	0.56	0.53	0.56
dw (mm)	4.65	5.74	4.65	4.65	7.5	4.65
tf1 (mm)	2.0	2.5	3.0	2.0	2.5	2.3
tf2 (mm)	3.0	6.0	6.0	8.0	9.8	4.0
D_hole (mm)	3.2	3.7	3.2	3.2	3.7	3.2
Ftu_bolt (psi)	160000	160000	160000	160000	160000	160000
Fsu_bolt (psi)	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt
Tmax (N-m)	0.75	1.4	0.75	0.75	1.4	0.75
Tmin (N-m)	0.675	1.26	0.675	0.675	1.26	0.675
Result of MoS						
MS2	90.291	15620	628.3	45.21	NA	116.38
MS4	0.693	0.684	0.701	0.682	NA	0.696
MS6	105.569	27120	733.6	79.96	NA	136.03
MS7	0.977	1.925	0.985	1.948	NA	0.979
MS8	9.351	137.0	57.62	3.441	NA	3.739
MS10	0.69	0.684	0.701	0.64	NA	0.659

Table 10-23: Fail-Safe analysis of each critical Joint (continued)

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JOINT	JOINT10b	JOINT11	JOINT12	JOINT13	JOIN14	JOINT15
bolt type	SPS96395-94C	SPS96395-96C	NAS1352N04	SPS96395-94C	NAS1352N04	NAS1352N04
insert type	MS21209-C0410	F-632-1	MS21209-C0415	MS21209-C0415	MS21209-C0410	MS21209-C0415
JOINT-FS	E80498	E80077	E80488	E80546	E80550	E80568
load case no.	1	71	66	49	50	60
P (N)	97.50	2.43	81.90	111.34	6.76	24.68
V (N)	43.91	199.58	139.73	232.72	135.58	24.46
D (mm)	2.845	3.51	2.845	2.845	2.845	2.845
L (mm)	6.35	9.53	6.35	11.11	6.35	9.53
Lt (mm)	6.35	9.53	6.35	11.11	6.35	9.53
Nt (1/in)	40	32	40	40	40	40
Lins (mm)	2.845	5.26	3.0	4.27	2.845	4.27
Fmin (mm)	4.039	4.902	4.039	4.039	4.039	4.039
lr (mm)	0.56	0.56	0.56	0.56	0.56	0.56
dw (mm)	4.65	5.74	4.65	4.65	4.65	4.65
tf1 (mm)	2.95	3.0	3.0	6.6	1.6	3.0
tf2 (mm)	4.0	5.5	3.0	3.1	11.4	5.0
D_hole (mm)	3.2	3.7	3.2	3.2	3.2	3.2
Ftu_bolt (psi)	160000	160000	160000	160000	160000	160000
Fsu_bolt (psi)	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt
Tmax (N-m)	0.75	1.4	0.75	0.75	0.75	0.75
Tmin (N-m)	0.675	1.26	0.675	0.675	0.675	0.675
Result of MoS						
MS2	34.046	2120	40.722	29.69	504.47	137.452
MS4	0.687	0.685	0.69	0.686	0.7	0.691
MS6	39.912	3682	47.704	52.77	589.07	241.579
MS7	0.97	1.926	0.973	1.953	0.984	1.962
MS8	39.743	12.448	11.804	6.687	12.195	72.141
MS10	0.687	0.683	0.688	0.677	0.698	0.691

Table 10-24: The Fail-Safe analysis of each critical Joint (continued)

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JOINT	JOINT16	JOINT17	JOINT18	JOINT19	JOINT12(for JOINT19 fail)
bolt type	NAS1352N04	NAS1352N08	NAS1351N3	E3-57	NAS1352N04
insert type	MS21209-C0410	MS21209-C0815	MS21209-F1-20	NA	MS21209-C0415
JOINT-FS	E80572	E80598	E80008	NA	E80487
load case no.	49	34	44	NA	FS2
P (N)	40.60	193.65	745.87	109.87	403.07
V (N)	42.82	138.86	83.72	41.09	28.536
D (mm)	2.845	4.17	4.826	NA	2.845
L (mm)	9.53	9.53	22.23	NA	6.35
Lt (mm)	9.53	9.53	22.23	NA	6.35
Nt (1/in)	40	32	32	NA	40
Lins (mm)	4.27	4.53	9.65	NA	3.0
Fmin (mm)	4.039	5.7	6.579	NA	4.039
Ir (mm)	0.56	0.53	0.89	NA	0.56
dw (mm)	4.65	7.5	7.92	NA	4.65
tf1 (mm)	4.6	5.0	13.	NA	3.0
tf2 (mm)	7.5	4.5	20.	NA	3.0
D_hole (mm)	3.2	4.7	5.3	NA	3.2
Ftu_bolt (psi)	160000	160000	160000	NA	160000
Fsu_bolt (psi)	0.6Ftu_bolt	0.6Ftu_bolt	0.6Ftu_bolt	NA	0.6Ftu_bolt
Tmax (N-m)	0.75	2.6	4.3	NA	0.75
Tmin (N-m)	0.675	2.34	3.87	NA	0.675
Result of MoS					
MS_FS 2	83.163	9.686	14.492	NA	7.477
MS_FS 3	0.691	40.497	0.673	NA	0.646
MS_FS 4	146.459	0.678	28.547	NA	9.435
MS_FS 5	1.963	45.286	2.192	NA	1.026
MS_FS 6	40.78	0.872	74.426	NA	61.694
MS_FS 7	10	30.03	10	NA	10
MS_FS 10	0.691	0.678	0.673	NA	0.646

Table 10-25: Fail-Safe analysis of each critical Joint (continued)

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10.4.3.6 JOINT 1 FS ADDITIONAL ANALYSIS

We also use the allowable of CS5108 to check joint safety for fail-safe configuration. The modified program listed as ANNEX-2 is used for MS_FS calculation with SFu=1.0, and the summary of MS_FS is list in the following TABLE 10-26. They are all positive.

MoS_FS	Value
Direct Tension Ultimate	MS2_FS
Total Tension Ultimate	MS4_FS
Shear Ultimate	MS8_FS
Combined shear, tension ultimate	MS10_FS

Table 10-26: MOS_FS of Joint1 based on bolt allowable

10.4.3.7 JOINT 9 FS ANALYSIS

The Joint 9 uses the captive bolt CA2261 dash 06 (0.138[in] with a pitch of 32[1/in]). The datasheet provide the minimum calculated allowable of:

Axial	Shear
4715 N	2846 N

Table 10-27: Allowable of Captive screw (from datasheet)

These values are used to verify the forces that come from the static analysis:

Axial	Shear
43.15N	233.39 N

Table 10-28: Applied forces on the Joint 9

$$R_{AX} = \frac{Axial_{app} \times FS_u}{Axial_{all}} = \frac{43.15 \times 1}{4715} = 0.01$$

$$R_{SH} = \frac{Shear_{app} \times FS_u}{Shear_{all}} = \frac{233.39 \times 1}{2846} = 0.08$$

$$R = R_{AX}^2 + R_{SH}^2 = 0.24$$

$$MoS_u = \sqrt{R} - 1 = 145$$

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11.MOS SUMMARY FOR STRESS ANALYSIS

The following table presents the summary of the margins of safety of the entire ACOP crate. In the table the values of Fty and Ftu have degraded by a factor of 0.97 and used Fty as Ftu for Lexan conservatively.

Margin of Safety for Stress Analysis (Nominal Configuration)									
Item	Max. Stress (MPa)	Critical Load Case	Material	Fty (MPa)	Ftu (MPa)	SFy	SFu	MoSy	MoSu
Locker	176.	21	AL 7075 T7351	381.2	454.8	1.25	2.0	0.733	0.292
Chassis	57.8	58	AL 6061 T6	234.1	254.1	1.25	2.0	2.24	1.20
Electronic Boards	5.18	73	FR4	N/A	194	N/A	2.0	N/A	17.73
PB-Heat Sink plate	72.1	73	AL 6061 T6	234.1	254.1	1.25	2.0	1.60	0.762
Hinge	138	52	AISI 316	461.5	829.4	1.25	2.0	1.675	2.00
Hinge adapters	499.	50	AM-355	1036.7	1136.8	1.25	2.0	0.662	0.139
Latch Pawl	55.9	59	AISI 304	173.6	488.3	1.25	2.0	1.484	3.368
Latch housing	24.1	59	AISI 316	461.5	829.4	1.25	2.0	14.32	16.21
LCD housing	28.3	66	AISI 304	173.6	488.3	1.25	2.0	3.907	7.627
Lexan	6.11	49	935A	61.1	NA	NA	2.0	NA	4.00
Door	155.	50	AL 7075 T7351	381.2	454.8	1.25	2.0	0.967	0.467
Front Panel	90.3	20	AL 7075 T7351	381.2	454.8	1.25	2.0	2.377	1.518
Margin of Safety for Stress Analysis (Fail-Safe Configuration)									
Locker	290.	FS1	AL 7075 T7351	381.2	454.8	NA	1.0	NA	0.568
Hinge	105	FS2	AISI 316	461.5	829.4	NA	1.0	NA	6.90
Latch Pawl	77.8	FS2	AISI 304	173.6	488.3	NA	1.0	NA	5.276

Table 11-1: MOS summary for stress analysis

All MoS are positive for each critical load case and comply with the positive margin of safety requirement. The minimum MoS is 0.139 occurred at the adapter of hinge for ultimate stress against the crew-induced pressure on the back cover of LCD in the open door configuration.

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Besides the stress analysis for the flange in the backplate, we also perform bearing, tension and shear out analysis to verify the nearby region of taper hole in the backplate and summarize the MoS in the next Table. They are all positive and comply with the requirement.

The Bearing, Tension and Shear Out Verification	
Nominal configuration	
MoS_bry for bearing yield	15.486
MoS_bru for bearing ultimate	12.103
MoS_lugty for lug tension yield	6.5
MoS_lugtu for lug tension ultimate	4.592
MoS_lugsy for lug shear out yield	3.179
MoS_lugsu for lug shear out ultimate	2.125
Fail-safe configuration	
MoS_bru for bearing ultimate	19.391
MoS_lugtu for lug tension ultimate	7.703
MoS_lugsu for lug shear out ultimate	3.863

Table 11-2: Summary of MoS for bearing, tension and shear out verification

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12.MOS SUMMARY FOR JOINT ANALYSIS

The following table presents the summary of the MoS of joints in the ACOP crate.

NOMINAL CONFIGURATION							
JOINT	JOINT1	JOINT2	JOINT3	JOINT4a	JOINT4b	JOINT5	JOINT6
bolt type	CS5108C-4-5	NAS1351N3	NAS1352N0 4	SPS96395 -94C	SPS96395 -94C	SPS96395 -94C	NAS1352N0 6
insert type	MS51831CA-202	MS21209F1 -15	MS21209- C0415	MS21209- C0410	MS21209- C0410	MS21209- C0410	MS21209- C0615
JOINT-CR	N107420	E80009	E80167	E80356	E80403	E80283	E80070
load case no.	21	54	21	53	52	18	55
applied P (N)	5394.3	177.74	224.9	10.08	12.04	154.58	87.99
applied V (N)	1639.6	429.09	291.13	643.07	800.25	189.53	246.98
MS1	0.004	13.551	2.311	73.113	45.296	3.833	11.473
MS2	0.963	31.506	6.597	168.494	140.902	10.053	28.286
MS3	1.356	38.008	8.116	202.393	169.283	12.263	34.144
MS4	0.355	0.681	0.625	0.696	1.093	0.654	0.667
MS5	0.08	0.266	0.238	0.273	0.571	0.253	0.255
MS6	1.57	29.601	7.757	196.86	164.652	11.902	49.862
MS7	0.774	0.583	0.873	0.98	1.442	0.931	1.896
MS8	2.576	6.358	2.073	0.391	0.118	3.72	4.434
MS9	10	10	10	10	10	10	10
MS10	0.32	0.671	0.523	0.139	0.021	0.62	0.644
FAIL-SAFE CONFIGURATION							
JOINT-FS	N107418	E80418	E80166	E80358	E80407	E80282	E80069
load case no.	FS1	54	21	53	52	18	55
applied P (N)	7595.78	9.52	199.84	46.39	60.04	37.43	0.33
applied V (N)	2107.17	346.08	212.41	456.36	603.88	172.83	19.45
MS2	1.788	357.93	16.099	72.658	55.912	90.291	15620
MS4	0.421	0.698	0.662	0.692	0.69	0.693	0.684
MS6	2.651	41.8	28.958	84.986	65.437	105.569	27120
MS7	0.861	0.982	1.912	0.975	0.973	0.977	1.925
MS8	4.565	4.169	7.423	2.92	1.963	9.351	137.0
MS10	0.41	0.669	0.656	0.63	0.561	0.69	0.684

Table 12-1: MoS summary of joint analysis

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NOMINAL CONFIGURATION							
JOINT	JOINT7	JOINT8	JOINT9	JOINT10a	JOINT10b	JOINT11	JOINT12
bolt type	NAS1352N04	NAS1352N04	CA2261-	SPS96395-94C	SPS96395-	SPS96395-	NAS1352N04
insert type	MS21209- C0410	MS21209- C0410	MS21209- C0615	MS21209- C0410	MS21209- C0410	F-632-1	MS21209- C0415
JOINT-CR	E80332	E80314	E80040	E80453	E80497	E80079	E80487
load case no.	6	58	2	2	1	71	66
P (N)	47.16	62.76	79.21	146.16	96.63	32.25	214.15
V (N)	23.61	362.14	697.06	74.3	54.79	165.87	47.95
MS1	14.809	10.723	NA	4.11	6.709	32.978	2.944
MS2	35.228	26.223	NA	10.689	16.681	78.904	6.978
MS3	42.473	31.667	NA	13.027	20.217	94.885	8.574
MS4	0.688	0.675	NA	0.658	0.674	0.679	0.758
MS5	0.27	0.261	NA	0.255	0.263	0.261	0.327
MS6	41.291	46.696	NA	12.646	19.64	137.77	12.901
MS7	0.971	1.934	NA	0.935	0.954	1.916	2.064
MS8	36.887	1.47	NA	11.039	15.326	7.091	17.655
MS9	10	10	NA	10	10	10	10
MS10	0.688	0.483	3.16*	0.656	0.673	0.672	0.758
FAIL-SAFE CONFIGURATION							
JOINT-FS	E80336	E80315	E80039	E80454	E80498	E80077	E80488
load case no.	6	58	2	2	1	71	66
P (N)	5.43	73.95	43.15	29.11	97.50	2.43	81.90
V (N)	30.52	402.86	233.39	377.5	43.91	199.58	139.73
MS2	628.3	45.21	NA	116.38	34.046	2120	40.722
MS4	0.701	0.682	NA	0.696	0.687	0.685	0.69
MS6	733.6	79.96	NA	136.03	39.912	3682	47.704
MS7	0.985	1.948	NA	0.979	0.97	1.926	0.973
MS8	57.62	3.441	NA	3.739	39.743	12.448	11.804
MS10	0.701	0.64	145*	0.659	0.687	0.683	0.688

Table 12-2: MOS summary of Joint analysis (continued)

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NOMINAL CONFIGURATION							
JOINT	JOINT13	JOIN14	JOINT15	JOINT16	JOINT17	JOINT18	JOINT19
bolt type	SPS96395-94C	NAS1352N04	NAS1352N04	NAS1352N04	NAS1352N08	NAS1351N3	E3-57 Latch
insert type	MS21209-C0415	MS21209-C0410	MS21209-C0415	MS21209-C0410	MS21209-C0815	MS21209-F1-20	NA
JOINT-CR	E80548	E80552	E80566	E80573	E80595	E80007	E80586
load case	49	50	60	49	34	44	65
P (N)	91.75	9.46	12.67	129.0	157.45	498.22	109.87
V (N)	225.12	121.84	9.04	98.39	114.72	79.78	41.09
MS1	6.745	80.039	55.984	4.552	0.953	3.843	NA
MS2	17.621	179.603	133.846	12.244	24.519	10.597	NA
MS3	21.346	215.723	160.816	14.893	29.523	12.916	NA
MS4	0.677	0.698	0.691	0.664	0.671	0.665	2.55*
MS5	0.264	0.274	0.269	0.257	0.258	0.258	NA
MS6	31.626	209.829	235.261	22.205	27.464	21.117	NA
MS7	1.939	0.982	1.962	1.916	0.864	2.175	NA
MS8	2.974	6.342	97.951	8.092	17.77	38.576	NA
MS9	10	10	10	10	10	10	NA
MS10	0.62	0.688	0.691	0.659	0.691	0.665	NA
FAIL-SAFE CONFIGURATION							
JOINT-FS	E80546	E80550	E80568	E80572	E80598	E80008	NA
load case	49	50	60	49	34	44	FS2
P (N)	111.34	6.76	24.68	40.60	193.65	745.87	215.9
V (N)	232.72	135.58	24.46	42.82	138.86	83.72	33.4
MS2	29.69	504.47	137.452	83.163	9.686	14.492	NA
MS4	0.686	0.7	0.691	0.691	40.497	0.673	2.613*
MS6	52.77	589.07	241.579	146.459	0.678	28.547	NA
MS7	1.953	0.984	1.962	1.963	45.286	2.192	NA
MS8	6.687	12.195	72.141	40.78	0.872	74.426	NA
MS10	0.677	0.698	0.691	0.691	0.678	0.673	NA

Table 12-3: MOS summary of Joint analysis (continued)

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The JOINT1 has also verified by the allowable ultimate force of CS5108C-4-6 (F.I.T. INC data sheet) and allowable of insert MS51831CA-202 (see RD9). The summary of MoS is list in the following table. In addition the MoS of JOINT19 based on product allowable is list in the next table. They are all compliant with the positive margin of safety requirement.

MoS	Value
Nominal configuration	
Direct Tension Ultimate	1.052
Direct Tension Yield	1.462
Total Tension Ultimate	0.416
Total Tension Yield	0.129
Shear Ultimate	3.119
Combined shear, tension ultimate	0.388
Fail-safe configuration	
Direct Tension Ultimate	1.914
Total Tension Ultimate	0.485
Shear Ultimate	5.41
Combined shear, tension ultimate	0.476

Table 12-4: MOS summary of Joint 1 based on CS5108C-4-6 captive bolt allowable

MoS	Value
Nominal configuration	
Ultimate allowable	2.55
Fail-safe configuration	
Ultimate allowable	2.613

Table 12-5: MOS summary of Joint 19 based on Southco E3-57 latch allowable

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13.COMPLIANCE MATRIX RESULTS

In the following table the results to the compliance matrix presented in the chapter 3 are provided:

Requirement	Reference	Item	Notes	Results	Ref page
Minimum natural frequency compatibility	AD 1 Section 4.1.1.1	EXPRESS payload frequency compatibility	Equal to or exceeding 35 Hz	128.97Hz	53
Minimum natural frequency compatibility	AD 1 Section 4.1.1.2	Middeck payload frequency compatibility	Equal to or exceeding 30 Hz	128.97Hz	53
Positive margin of safety	AD 1 Section 4.1.2.1	EXPRESS rack low frequency launch and landing loads	Factor of safety for yielding =1.25 Factor of safety for ultimate =2.0	OK	52
Positive margin of safety	AD 1 Section 4.1.2.2	Middeck low frequency launch and landing loads	Factor of safety for yielding =1.25 Factor of safety for ultimate =2.0	OK	52
Positive margin of safety	AD 1 Section 4.2.1	Middeck emergency landing load		LC 25-LC 30	43
Positive margin of safety	AD 1 Section 4.2.2	EXPRESS rack emergency landing load	May be neglected for analysis using low frequency loads	NA	41
Positive margin of safety	AD 1 Section 4.3.1	EXPRESS rack random vibration loads	Combined into EXPRESS low frequency loads	LC 1-LC 24	41
Positive margin of safety	AD 1 Section 4.3.2	Middeck random vibration loads	Has been included into Middeck low frequency liftoff loads.	NA	42
Limitation of mass-to-CG	AD 1 Section 4.4	Payload mass properties limits	Mass-to-CG relationship conformation	Ok	38
Positive margin of safety	AD 1 Section 4.5	On-orbit load	Consider crew-induced loads Neglect low frequency load	LC 31-LC 50	44
Positive margin of safety	RD 16 Section 4.3	Depressurization / Re-pressurization load	ACOP is an open structure and need not consider this load	NA	45
Positive margin of safety	RD 16 Section 4.2.6	Thermal load	Use material derating factor to cover thermal effect	NA	45
Positive margin of safety	AD 1 Section 4.9.1	Ground handling load	Level of Ground handling load is low and not considered, with the exception of the LC 51	LC 51	46
Positive margin of safety	RD 16 Section 7.2.2	Test load	Four kinds of test load considered	LC 52-LC 75	47

Table 13-1: Compliance Matrix

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10.CONCLUSIONS AND COMMENTS

In this report we perform the dynamic, static and joint analyses to verify the ACOP crate structural safety.

- (1) For the dynamic verification the first natural frequency of the ACOP crate is 128.97Hz; the requirement of 35 Hz is met. The modal analysis is performed even in the JOINT1 Fail-Safe (the first natural frequency is 87.83Hz), and in the JOINT19 fail-safe analysis (the first natural frequency is 104.1Hz); also in the Fail-Safe configuration the first natural frequency remains greater than 35Hz and comply with the requirement.
- (2) The ACOP structure conform to the mass-to-CG relationship required in AD1 (see section 6.9).
- (3) After evaluation for the loads defined in AD1 chapter 4 and AD16 chapter 7, we have totally 75 load cases for ACOP structural analysis. The main critical load cases include Lift-off loads for Express Rack, Emergency landing load for Middeck, Crew-induced loads and Qualification for Acceptance Vibration Test loads. The factors of safety used in ACOP structural analysis is summarized in chapter 8.1 .
- (4) The MoS of ACOP structure with the modified small handle are positive for all critical loads and compliant with the positive margin of safety requirement.
 - (i) For the stress verification the minimum MoS is 0.032 occurred at the adapter of hinge for ultimate stress against the crew-induced pressure on the back cover of LCD in the open door configuration. All MoS are positive in the stress verification for the nominal and fail-safe configuration and comply with the positive margin of safety requirement (see section 10.2 and chapter 11).
 - (ii) The bearing, tension and shear out verifications for lug nearby the taper hole in the interface of ACOP and EXPRESS Rack have performed in the section 10.2 and all MoS are positive. (see *Table 10-3*)
 - (iii)The joint verification has performed by the program complied with AD 12 and by product allowable. Sum up the joint analysis for nominal configuration, all MoSs of joints of ACOP with the small handle modification are positive and comply with the positive margin of safety requirement. The minimum MoS is 0.004 for joint separation occurred at JOINT1 on the backplate. (see section 10.3.1)
 - (iv) For the joint verification of the fail-safe configuration the joints of ACOP structure with modified small handle comply with the positive margin of safety requirement. The minimum MoS is 0.41 for combined shear, tension, bending ultimate occurred at JOINT1 on the backplate. (see section 10.3.2)

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ANNEX 1.

JOINT ANALYSIS EXAMPLE

CHECK JOINT1 (CS5108 Material-A286), Insert MS51831CA-202

Flange 1

Part number:

Material:

Flange 2

Part number:

Material:

Loads

Applied tensile load

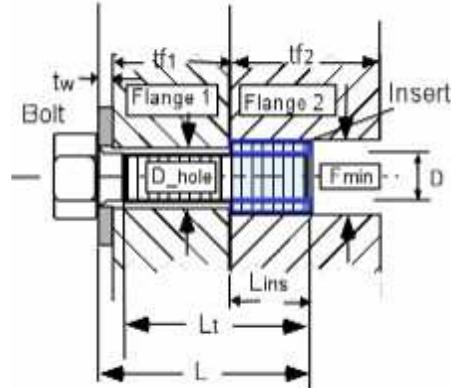
$$P := 5394.3 \text{ N}$$

Applied shear load

$$V := 1639.6 \text{ N}$$

Applied bending moment

$$M := 0 \cdot \text{m} \cdot \text{N}$$



Factors of Safety

Ultimate	SFu := 2.0	Yield	SFy := 1.25	Assembly	Temp_initial := 70 · deg
Joint Separation	SFsep := 1.2	Fitting factor	FF := 1.15	Maximum	Temp_max := 120 · deg
				Minimum	Temp_min := -30 · deg

Bolt and Insert Data

Nominal diameter of bolt	D := 0.25 in	Number of threads/inch	Nt := 28 · $\frac{1}{\text{in}}$
Total length of bolt	L := 17.45 mm	Length of insert	Lins := 9.53 mm
Threaded length	Lt := 12.7 mm	Min. external diameter of insert	Fmin := 8.382 mm
(If bolt is fully threaded, input Lt = L)		Depth of recess for insert	Ir := 0.76 mm

 Reference:E:\ACOP\EM2\bolt_analysis\thread_data_cgs.mcd(R)

$$E_{max} = 5.761 \times 10^{-3} \text{ m} \quad K_{nmin} = 5.367 \times 10^{-3} \text{ m} \quad tol_b = 1.651 \times 10^{-4} \text{ m} \quad tol_n = 1.956 \times 10^{-4} \text{ m}$$

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Washer Data

Thickness of washer

$$tw := 0.0 \cdot \text{mm}$$

Outer Diameter of washer

$$Dw := 0.0 \cdot \text{mm}$$

Inner Diameter of washer

$$Dwi := 0.0 \cdot \text{mm}$$

Bolt head dia. across flats

$$dw := 9.53 \cdot \text{mm}$$

Flange data

Thickness of flange 1

$$tf1 := 6.3 \cdot \text{mm}$$

Thickness of flange 2

$$tf2 := 13 \cdot \text{mm}$$

Diameter of hole

$$D_{\text{hole}} := 6.8 \cdot \text{mm}$$

(used only if there is no washer)

Note: If there is no washer, tw, Dw, and Dwi should be zero.

Material Property Data

Bolt

Temperature correction factor for bolt strength ultimate

$$TSu_{\text{bolt}} := 0.97$$

yield

$$TSy_{\text{bolt}} := 0.97$$

Bolt ultimate tensile allowable stress

$$Ftu_{\text{bolt}} := 160000 \cdot \text{psi}$$

Bolt ultimate shear allowable stress

$$Fsu_{\text{bolt}} := 0.6 \cdot Ftu_{\text{bol}}$$

Bolt yield tensile allowable

$$Fty_{\text{bolt}} := 120000 \cdot \text{psi}$$

Temperature correction factor for bolt modulus

$$TE_{\text{bolt}} := 0.97$$

Modulus of elasticity of bolt

$$E_{\text{bolt}} := (29.1 \cdot 10^6 \cdot \text{psi})$$

Thermal coeffecient for bolt:

Insert

Temperature correction factor for insert strength

$$TS_{\text{ins}} := 0.97$$

Ultimate tensile allowable stress

$$Ftu_{\text{ins}} := 160000 \cdot \text{psi}$$

Temperature correction factor for washer modulus

$$TE_{\text{washer}} := 1.0$$

Ultimate shear allowable stress

$$Fsu_{\text{ins}} := 0.6 \cdot Ftu_{\text{ins}}$$

Modulus of elasticity of washer

$$E_{\text{washer}} := (29.1 \cdot 10^6 \cdot \text{psi})$$

Washer

Flanges

Temperature correction factor for flange 1

$$Tf1E := 1.0 \quad (\text{modulus})$$

$$Tf2s := 0.97 \quad (\text{strength})$$

Temperature correction factor for flange 2

$$Tf2E := 1.0 \quad (\text{modulus})$$

$$Fsu_{\text{f2}} := 38000 \cdot \text{psi}$$

Modulus of elasticity for the parts in the joint

$$E_{\text{flange1}} := (10.3 \cdot 10^6 \cdot \text{psi})$$

$$E_{\text{flange2}} := (10.3 \cdot 10^6 \cdot \text{psi})$$

Coefficient of thermal expansion for flanges

$$\alpha_{\text{bolt_hot}} := 8.75 \cdot 10^{-6} \cdot \frac{\text{in}}{\text{in}} \cdot \frac{\text{deg}}{\text{in}}$$

$\alpha_{\text{flange1_hot}} := 12.45 \cdot 10^{-6} \cdot \frac{\text{in}}{\text{in}} \cdot \frac{\text{deg}}{\text{in}}$	$\alpha_{\text{flange2_hot}} := 12.45 \cdot 10^{-6} \cdot \frac{\text{in}}{\text{in}} \cdot \frac{\text{deg}}{\text{in}}$
$\alpha_{\text{flange1_cold}} := 11.9 \cdot 10^{-6} \cdot \frac{\text{in}}{\text{in}} \cdot \frac{\text{deg}}{\text{in}}$	$\alpha_{\text{flange2_cold}} := 11.9 \cdot 10^{-6} \cdot \frac{\text{in}}{\text{in}} \cdot \frac{\text{deg}}{\text{in}}$



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Torque/Preload data

Maximum torque $T_{\max} := 1 \text{ Nm} \cdot \text{N}$ Loading plane factor: $n := 0.5$

$$\text{Minimum torque} \quad T_{\min} := 10 \cdot m \cdot N \quad \text{Preload Uncertainty:} \quad \Gamma := 0.25$$

Torque coefficient: $k \approx 0.15$

Loading plane factor: n := 0.5

Minimum pitch diameter of bolt	Max. inner diameter of insert	Knmax := Knmin + 0.5 · tol_r
$Esm_{min} := Emax - 0.5 \cdot tol_b$	$Enmax := Emax + 0.5 \cdot tol_r$	$Min. outer diameter of bolt$
Max. pitch diameter of insert		

$$E_{tu,bolt} := E_{tu,bolt} \cdot TS_{u,bolt} \quad D_{min} := D - 0.5 \cdot tol$$

Bolt tension allowable yield $E_{ty, bolt} := E_{ty, bolt} \cdot TS_{y, bolt}$

Bolt shear allowable ultimate $F_{su,bolt} := F_{su,bolt} \cdot TS_{u,bolt}$

Modulus of elasticity of bolt E_{bolt} ≈ Modulus of elasticity of TE bolt $E_{\text{TE,bolt}}$

Insert tension allowable ultimate $E_{tu_ins} := E_{tu_ins} \cdot TS_inp$

Insert shear allowable TSu_{ins} = TSu_{ins} · TS_{in}

$$E_{\text{Washer}} := E_{\text{Washer}} \cdot TE_{\text{Washer}}$$

Modulus of elasticity of parts in the joint $E_{\text{flange1}} = E_{\text{flange1_H}}$

E_flange2:= E_flange2 Tf2F

$$\text{Thickness of washer and flange} \quad h := t_w + t_f \quad (\text{Re})$$

$$\text{grip length} := \begin{cases} \text{Lins} & \text{if } L \geq (h + lr + \text{Lins}) \\ L - h - lr & \text{otherwise} \end{cases}$$

$$\text{Effective grip length} \quad l := \begin{cases} h + \frac{tf2}{2} & \text{if } tf2 < D \\ h + lr + \frac{g}{2} & \text{otherwise} \end{cases}$$

Unthreaded length(shank)

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If the bolt is fully threaded the unthreaded shank length l_d is zero and the program will check it by the if statement.

$$l_d := \begin{cases} 0.0 \text{ in} & \text{if } l_t \geq L \\ l_d & \text{otherwise} \end{cases}$$

Length of useful threaded portion $l_t := l - l_d$

Unthreaded tensile area: $A_d := \pi \cdot \left(\frac{D}{2} \right)^2$

$$A_{t1} := 0.7854 \cdot \left(D - \frac{0.9743}{N_t} \right)^2 \quad (\text{Ref.4, page 1325, equation 2a, 2b})$$

$$A_{t2} := \pi \cdot \left(\frac{\frac{E_{\min}}{2} - 0.16238}{N_t} \right)^2$$

Tensile area: $A_t := \begin{cases} A_{t1} & \text{if } F_{tu_bolt} \leq 100000 \text{ psi} \\ A_{t2} & \text{otherwise} \end{cases}$

Shear area: $A_s := \pi \cdot \left(\frac{D - 1.299038 \cdot \frac{1}{N_t}}{2} \right)^2$

Moment of inertia of bolt cross section: $I := \frac{\pi \cdot \left(D - 0.9743 \cdot \frac{1}{N_t} \right)^4}{64}$

Distance to outer fiber: $\zeta := \frac{D - 0.9743 \cdot \frac{1}{N_t}}{2}$

Bolt tensile ultimate strength: $P_{At} := F_{tu_bolt} \cdot A_t$

Bolt tensile yield strength: $P_{Ay} := F_{ty_bolt} \cdot A_t = \frac{K_b}{K_b + K_j}$

Bolt shear strength ultimate: $V_{Au} := F_{su_bolt} \cdot A_s$

This gives the washer area as:

Bending moment allowable ultimate: $M_{Au} := F_{tu_bolt} \cdot \frac{I}{c}$

Joint load factor:

The joint load factor (ϕ) is specified by Ref 1 as: $A_{washer} := \pi \cdot \frac{D_w^2 - D_{wi}^2}{4}$

$\alpha_{cone} := 30 \text{ deg}$



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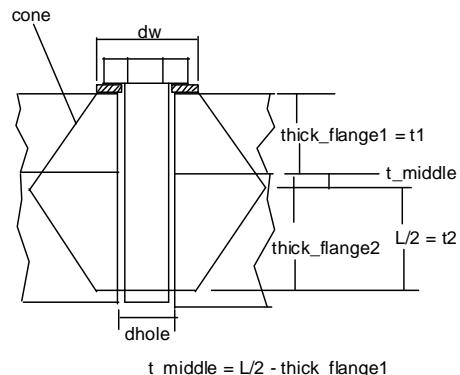
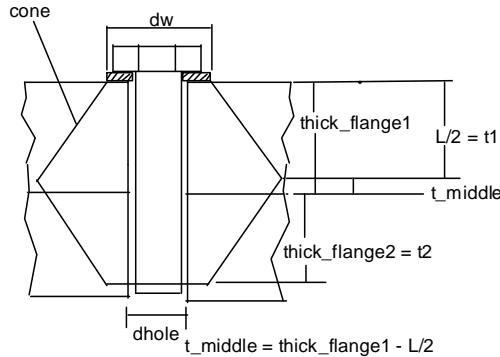
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$$L_{\text{thick}} := t_{f1} + l_r + \frac{g}{2}$$

The mid-plane of the frustum may lie in either flange1 or flange2.
If the material properties of the two are different then this must be accounted for.

$$t_1 := \text{if} \left[\left(\frac{L_{\text{thick}}}{2} > t_{f1} \right), t_{f1}, \frac{L_{\text{thick}}}{2} \right]$$

thickness of flange1
frustum

$$t_2 := \text{if} \left[\left(\frac{L_{\text{thick}}}{2} > t_{f1} \right), \frac{L_{\text{thick}}}{2}, \frac{g}{2} \right]$$

thickness of flange2
frustum

Properties for middle of flange1 and flange2 frustum

$$D_w := \begin{cases} dw & \text{if } Dw = 0.0 \cdot \text{in} \\ Dw & \text{otherwise} \end{cases}$$

$$E_{\text{middle}} := \text{if} \left[\left(\frac{L_{\text{thick}}}{2} > t_{f1} \right), E_{\text{flange2}}, E_{\text{flange1}} \right]$$

$$D_{\text{middle}} := \text{if} \left[\left(\frac{L_{\text{thick}}}{2} > t_{f1} \right), Dw + 2 \cdot t_1 \cdot \tan(\alpha_{\text{cone}}), Dw + 2 \cdot t_2 \cdot \tan(\alpha_{\text{cone}}) \right]$$

$$t_{\text{middle}} := \text{if} \left[\left(\frac{L_{\text{thick}}}{2} > t_{f1} \right), \frac{L_{\text{thick}}}{2} - t_{f1}, t_{f1} - \frac{L_{\text{thick}}}{2} \right]$$

The stiffness for each of the members is then given by:

$$k_{\text{flange1}} := \frac{\pi \cdot E_{\text{flange1}} \cdot D_{\text{hole}} \cdot \tan(\alpha_{\text{cone}})}{\ln \left[\frac{(2 \cdot t_1 \cdot \tan(\alpha_{\text{cone}}) + Dw - D_{\text{hole}}) \cdot (Dw + D_{\text{hole}})}{(2 \cdot t_1 \cdot \tan(\alpha_{\text{cone}}) + Dw + D_{\text{hole}}) \cdot (Dw - D_{\text{hole}})} \right]}$$

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$$k_{\text{flange2}} := \frac{\pi \cdot E_{\text{flange2}} D_{\text{hole}} \cdot \tan(\alpha_{\text{cone}})}{\ln \left[\frac{(2 \cdot t_2 \cdot \tan(\alpha_{\text{cone}}) + D_w - D_{\text{hole}}) \cdot (D_w + D_{\text{hole}})}{(2 \cdot t_2 \cdot \tan(\alpha_{\text{cone}}) + D_w + D_{\text{hole}}) \cdot (D_w - D_{\text{hole}})} \right]}$$

$$k_{\text{middle}} := \text{if } t_{\text{middle}} = 0 \text{in}, 10^{14} \cdot \frac{\text{lbf}}{\text{in}}, \frac{\pi \cdot E_{\text{middle}} D_{\text{hole}} \cdot \tan(\alpha_{\text{cone}})}{\ln \left[\frac{(2 \cdot t_{\text{middle}} \cdot \tan(\alpha_{\text{cone}}) + D_{\text{middle}} - D_{\text{hole}}) \cdot (D_{\text{middle}} + D_{\text{hole}})}{(2 \cdot t_{\text{middle}} \cdot \tan(\alpha_{\text{cone}}) + D_{\text{middle}} + D_{\text{hole}}) \cdot (D_{\text{middle}} - D_{\text{hole}})} \right]}$$

NOTE: If statement to check if $k_{\text{flange1}} = k_{\text{flange2}}$

The stiffness for the washer, treating it as a cylinder, is:

$$k_{\text{washer}} := \frac{A_{\text{washer}} \cdot E_{\text{washer}}}{tw}$$

~~k_{washer}~~ $0.0 \cdot \frac{\text{lbf}}{\text{in}}$ $tw = 0.0\text{in}$

The joint stiffness will be

$$K_j := \begin{cases} \frac{1}{\frac{1}{k_{\text{flange1}}} + \frac{1}{k_{\text{flange2}}} + \frac{1}{k_{\text{middle}}}} & \text{if } tw = 0\text{in} \\ \frac{1}{\frac{1}{k_{\text{flange1}}} + \frac{1}{k_{\text{flange2}}} + \frac{1}{k_{\text{middle}}} + \frac{1}{k_{\text{washer}}}} & \text{otherwise} \end{cases}$$

The joint load factor will then be:

$$\phi := \frac{k_{\text{bolt}}}{K_j + k_{\text{bolt}}}$$

stiffness of joint

$$K_{\text{therm}} := \frac{k_{\text{bolt}} \cdot K_j}{k_{\text{bolt}} + K_j}$$

Calculation of Preload on the Bolt:

Increase in preload due to increase in temperature

$$Pthr_1 := \left[\left[(tf1) \cdot (\text{Temp_max} - \text{Temp_initial}) \cdot (\alpha_{\text{flange1_hot}} - \alpha_{\text{bolt_hot}}) \right] \dots \right] \cdot K_{\text{therm}} + (g + lr) \cdot (\text{Temp_max} - \text{Temp_initial}) \cdot (\alpha_{\text{flange2_hot}} - \alpha_{\text{bolt_hot}})$$

Decrease in preload due to reduction in temperature:

$$Pthr_2 := \left[\left[(tf1) \cdot (\text{Temp_min} - \text{Temp_initial}) \cdot (\alpha_{\text{flange1_cold}} - \alpha_{\text{bolt_cold}}) \dots \right] \dots \right] \cdot K_{\text{therm}} + (g + lr) \cdot (\text{Temp_min} - \text{Temp_initial}) \cdot (\alpha_{\text{flange2_cold}} - \alpha_{\text{bolt_cold}})$$

$$Pthr_{\text{pos}} := \begin{cases} Pthr_1 & \text{if } (Pthr_1 \geq 0 \text{lbf}) \cdot (Pthr_2 \leq 0 \text{lbf}) \\ Pthr_2 & \text{if } (Pthr_1 \leq 0 \text{lbf}) \cdot (Pthr_2 \geq 0 \text{lbf}) \\ \max \left(\begin{pmatrix} Pthr_1 \\ Pthr_2 \end{pmatrix} \right) & \text{if } (Pthr_1 > 0 \text{lbf}) \cdot (Pthr_2 > 0 \text{lbf}) \\ 0 \cdot \text{lbf} & \text{otherwise} \end{cases}$$

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$$\text{Pthr_neg} := \begin{cases} \text{Pthr_2 if } (\text{Pthr_1} \geq 0 \cdot \text{lbf}) \cdot (\text{Pthr_2} \leq 0 \cdot \text{lbf}) \\ \text{Pthr_1 if } (\text{Pthr_1} \leq 0 \cdot \text{lbf}) \cdot (\text{Pthr_2} \geq 0 \cdot \text{lbf}) \\ 0 \cdot \text{lbf if } (\text{Pthr_1} > 0 \cdot \text{lbf}) \cdot (\text{Pthr_2} > 0 \cdot \text{lbf}) \\ \min\left(\frac{\text{Pthr_1}}{\text{Pthr_2}}\right) \text{ otherwise} \end{cases}$$

Maximum preload at max. temp. :

$$\text{PLDmax} := (1 + \Gamma) \cdot \frac{T_{\max}}{k \cdot D} + \text{Pthr_pos} \quad (\text{Ref.1, page 3-5})$$

Max. preload at room temp.

$$\text{PLDmaxRT} := (1 + \Gamma) \cdot \frac{T_{\max}}{k \cdot D}$$

Preload loss will be 5% of max:

$$\text{Ploss} := \text{PLDmaxRT} \cdot .05$$

Minimum preload

$$\text{PLDmin} := (1 - \Gamma) \cdot \frac{T_{\min}}{k \cdot D} + \text{Pthr_neg} - \text{Ploss}$$

Check to see if Min. preload is negative

$$\text{PLDmin} := \begin{cases} \text{PLDmin if } \text{PLDmin} > 0.0 \cdot \text{lbf} \\ 0.0 \cdot \text{lbf if } \text{PLDmin} \leq 0.0 \cdot \text{lbf} \end{cases}$$

Check for thread shear of bolt on internal threads of Insert

Calculation for Thread shear pullout strength

Insert and Bolt are same strength

Thread engagement length

$$\text{Le1} := \frac{4 \cdot \text{At}}{\pi \cdot \text{Emax}}$$

Shear pullout area

$$\text{Ats1} := \frac{\pi \cdot \text{Emax} \cdot \text{Le1}}{2}$$

Insert stronger than Bolt

Thread engagement length

$$\text{Le2} := \frac{2 \cdot \text{At}}{\pi \cdot \text{Nt} \cdot \text{Knmax} \cdot \left[\left(\frac{1}{2 \cdot \text{Nt}} \right) + 0.57735 \cdot (\text{Esmin} - \text{Knmax}) \right]}$$

Shear pullout area

$$\text{Ats2} := \pi \cdot \text{Nt} \cdot \text{Le2} \cdot \text{Knmax} \cdot \left[\frac{1}{2 \cdot \text{Nt}} + 0.57735 \cdot (\text{Esmin} - \text{Knmax}) \right]$$

Insert weaker than Bolt

Thread engagement length

$$\text{Le3} := \frac{\text{Ftu_bolt} \cdot 2 \cdot \text{At}}{\text{Ftu_ins} \cdot \pi \cdot \text{Nt} \cdot \text{Dsmin} \cdot \left[\left(\frac{1}{2 \cdot \text{Nt}} \right) + 0.57735 \cdot (\text{Dsmin} - \text{Enmax}) \right]}$$

Shear pullout area

$$\text{Ats3} := \pi \cdot \text{Nt} \cdot \text{Le3} \cdot \text{Dsmin} \cdot \left[\frac{1}{2 \cdot \text{Nt}} + 0.57735 \cdot (\text{Dsmin} - \text{Enmax}) \right]$$

Determine if insert is stronger , equal or weaker than bolt

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$$PAs1 := F_{su_bolt} \cdot A_{ts1} \quad (\text{Bolt and insert equal strength})$$

$$PAs2 := F_{su_bolt} \cdot A_{ts2} \quad (\text{Insert stronger than bolt})$$

$$PAs3 := F_{su_ins} \cdot A_{ts3} \quad (\text{Insert weaker than bolt})$$

Minimum thread shear strength required to develop the full strength of the bolt:

$$PAsi := \begin{cases} PAs2 & \text{if } F_{tu_ins} > F_{tu_bol} \\ PAs3 & \text{if } F_{tu_ins} < F_{tu_bol} \\ PAs1 & \text{otherwise} \end{cases}$$

$$\text{Actual thread engagement length} \quad L_{ths} := L - (t_w + t_f1 + l_r)$$

$$\text{Actual Thread shear pullout area} \quad A_{ths} := \pi \cdot E_{max} \cdot \frac{L_{ths}}{2}$$

Check if the actual shear pullout load is smaller than the minimum required strength

$$P_{ths1} := F_{su_bolt} \cdot A_{ths}$$

$$P_{ths2} := F_{su_bolt} \cdot A_{ths}$$

$$P_{ths3} := F_{su_ins} \cdot A_{ths}$$

$$P_{ths} := \begin{cases} P_{ths2} & \text{if } F_{su_ins} > F_{su_bol} \\ P_{ths3} & \text{if } F_{su_ins} < F_{su_bol} \\ P_{ths1} & \text{otherwise} \end{cases}$$

Check for thread shear of insert on parent metal threads

$$\text{Length of thread engagement} \quad L_{eng1} := L_{in}$$

$$\text{Area of thread shear} \quad A_{tse} := \pi \cdot F_{min} \cdot \frac{L_{eng1}}{2}$$

$$\text{Parent metal thread shear strength:} \quad P_{ase} := A_{tse} \cdot F_{su_f2} \cdot F_{f2s}$$

Check if thread shear of insert or parent metal threads are critical

$$P_{pths} := \begin{cases} P_{ths} & \text{if } P_{ths} < P_{ase} \\ P_{ase} & \text{otherwise} \end{cases}$$

Check for length of bolt for insert

$$\text{Length_check} := \begin{cases} \text{"Bolt length is sufficient!"} & \text{if } L \geq (t_w + t_f1 + l_r + 0.75 \cdot L_{in}) \\ \text{"Bolt length should be increased!"} & \text{otherwise} \end{cases}$$

Total tensile load on bolt

$$P_b := PLD_{max} + n \cdot \phi \cdot (SF_u \cdot P \cdot FF)$$

Total Yield tensile load on bolt

$$P_{by} := PLD_{max} + n \cdot \phi \cdot (SF_y \cdot P \cdot FF)$$

Joint Separation load

$$P_{sep} := P \cdot SF_{sep}$$

Margins of Safety on the bolt

Margin of safety on joint separation:

$$MS_1 := \begin{cases} 10.0 & \text{if } P = 0 \cdot lbf \\ \frac{PLD_{min}}{(1 - n \cdot \phi) \cdot P_{sep} \cdot FF} - 1 & \text{otherwise} \end{cases}$$

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Margin of safety on applied tension load
ultimate:

$$\text{MS}_2 := \begin{cases} 10.0 & \text{if } P = 0 \cdot \text{lbf} \\ \frac{P_{At}}{(SF_u \cdot P) \cdot FF} - 1 & \text{otherwise} \end{cases}$$

Ratio on applied tension ult: $\text{RAU}_1 := \frac{SF_u \cdot P \cdot FF}{P_{At}}$

Margin of safety on applied tension load
Yield:

$$\text{MS}_3 := \begin{cases} 10.0 & \text{if } P = 0 \cdot \text{lbf} \\ \frac{P_{Ay}}{(SF_y \cdot P) \cdot FF} - 1 & \text{otherwise} \end{cases}$$

Ratio on applied tension yield: $\text{Ray}_1 := \frac{SF_y \cdot P \cdot FF}{P_{Ay}}$

Margin of safety on total tension load
ultimate:

$$\text{MS}_4 := \frac{P_{At}}{P_b} - 1$$

Ratio on total tension ult: $\text{RAU}_2 := \frac{P_b}{P_{At}}$

Margin of safety on total tension load
(Yield):

$$\text{MS}_5 := \frac{P_{Ay}}{P_{by}} - 1$$

Ratio on total tension (Yield): $\text{Ray}_2 := \frac{P_{by}}{P_{Ay}}$

Ratio on preload
(Yield):

$$\text{Ray}_3 := \frac{PLD_{max}}{P_{Ay}}$$

Margin of safety on thread shear using direct
tension only

$$\text{MS}_6 := \begin{cases} 10.0 & \text{if } P = 0 \cdot \text{lbf} \\ \frac{P_{pths}}{(SF_u \cdot P) \cdot FF} - 1 & \text{otherwise} \end{cases}$$

Margin is based upon the total tension
load

$$\text{MS}_7 := \frac{P_{pths}}{P_b} - 1$$

Margin of safety on applied shear load
ultimate:

$$\text{MS}_8 := \begin{cases} 10.0 & \text{if } V = 0 \cdot \text{lbf} \\ \frac{V_{Au}}{(SF_u \cdot |V|) \cdot FF} - 1 & \text{otherwise} \end{cases}$$

Shear ratio ult.: $R_{su} := \frac{SF_u \cdot |V| \cdot FF}{V_{Au}}$

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Margin of safety on applied moment
ultimate:

$$\text{MS9} := \begin{cases} 10.0 & \text{if } M = 0 \text{ in-lbf} \\ \frac{MA_u}{SF_u \cdot |M| \cdot FF} - 1 & \text{otherwise} \end{cases}$$

Moment ratio: $R_{bu} := \frac{SF_u \cdot |M| \cdot FF}{MA_u}$

Guess K

$$K_{ru} := 1.0$$

Given

$$(K_{ru} \cdot R_{su})^3 + [K_{ru} \cdot (\max(RAU) + R_{bu})]^2 = 1$$

$$K_{ru} := \text{Find}(K_{ru})$$

Margin of safety on combined loading
ultimate:

$$\text{MS10} := K_{ru} - 1$$

Failure_Mode :=

"Joint Separation"	if $MS_1 = \min(MS)$
"Direct Tension Ultimate"	if $MS_2 = \min(MS)$
"Direct Tension Yield"	if $MS_3 = \min(MS)$
"Total Tension Ultimate"	if $MS_4 = \min(MS)$
"Total Tension Yield"	if $MS_5 = \min(MS)$
"Direct Thread Shear Ultimate"	if $MS_6 = \min(MS)$
"Total Thread Shear Ultimate"	if $MS_7 = \min(MS)$
"Shear Ultimate"	if $MS_8 = \min(MS)$
"Bending Ultimate"	if $MS_9 = \min(MS)$
"Combined Shear Tension Bending Ultimate"	
if $MS_{10} = \min(MS)$	

Bolt Load data

Bolt/joint stiffness factor	$\phi = 0.458$	Preload due to temperature	$P_{thr_pos} = 703.1\text{N}$
Max. preload	$PLD_{max} = 15138.8\text{N}$		$P_{thr_neg} = -1387.2\text{N}$
Min. preload	$PLD_{min} = 5765.1\text{N}$	Uncertainty factor	$\Gamma = 0.25$
Joint separation load	$P_{sep} = 6.473 \times 10^3 \text{ N}$	Torque coefficient	$k = 0.15$
Max. load on the bolt(ultimate)	$P_b = 17977.5\text{N}$	Loading plane factor	$n = 0.5$
Max. load on the bolt(yield)	$P_{by} = 16913\text{N}$	Thread shear pullout load of bolt or insert	$P_{ths} = 60363.5\text{N}$
Bolt ultimate tensile strength	$P_{At} = 24357.9\text{N}$	Thread shear pullout load in parent metal	$P_{pths} = 31888.5\text{N}$

Length_check = "Bolt length is sufficient"

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Summary of Margins for bolt:

Joint separation	$MS_1 = 4.214 \times 10^{-3}$	Direct Thread shear Ultimate	$MS_6 = 1.57$
Direct Tension Ultimate	$MS_2 = 0.963$	Total Thread shear Ultimate	$MS_7 = 0.774$
Direct Tension Yield	$MS_3 = 1.356$	Shear Ultimate	$MS_8 = 2.576$
Total Tension Ultimate	$MS_4 = 0.355$	Bending Ultimate	$MS_9 = 10$
Total Tension Yield	$MS_5 = 0.08$	Combined shear, tension and bending ultimate	$MS_{10} = 0.32$

Determination of the smallest margin of safety for the bolt, and the failure mode:

$$MS_{\text{bolt}} := \min(MS)$$

$$MS_{\text{bolt}} = 4.214 \times 10^{-3} \quad \text{Failure_Mode} = \text{"Joint Separation"}$$

Fail-safe Analysis

Fail-safe Loads

$$\text{Applied tensile load} \quad P_{\text{FS}} := 7595.78 \cdot \text{N}$$

$$\text{Applied shear load} \quad V_{\text{FS}} := 2107.17 \cdot \text{N}$$

$$\text{Applied bending moment} \quad M_{\text{FS}} := 0 \cdot \text{N} \cdot \text{m}$$

Fail-safe Factors of Safety

$$\text{Ultimate} \quad SF_{\text{U}}_{\text{FS}} := 1.0$$

$$\text{Joint Separation} \quad SF_{\text{sep}}_{\text{FS}} := 1.0$$

Margins of Safety on the bolt

$$\text{Total tensile load on bolt} \quad Pb_{\text{FS}} := PLD_{\text{max}} + n \cdot \phi \cdot (SF_{\text{U}}_{\text{FS}} \cdot P_{\text{FS}} \cdot FF)$$

$$\text{Joint Separation load} \quad P_{\text{sep}}_{\text{FS}} := P_{\text{FS}} \cdot SF_{\text{sep}}_{\text{FS}}$$

$$\text{Margin of safety on joint separation:} \quad MS_{\text{FS1}} := \begin{cases} 10.0 & \text{if } P_{\text{FS}} = 0 \cdot \text{lbf} \\ \frac{PLD_{\text{min}}}{(1 - n \cdot \phi) \cdot P_{\text{sep}}_{\text{FS}} \cdot FF} - 1 & \text{otherwise} \end{cases}$$

$$\text{Margin of safety on applied tension load ultimate:} \quad MS_{\text{FS2}} := \begin{cases} 10.0 & \text{if } P_{\text{FS}} = 0 \cdot \text{lbf} \\ \frac{PAt}{(SF_{\text{U}}_{\text{FS}} \cdot P_{\text{FS}}) \cdot FF} - 1 & \text{otherwise} \end{cases}$$

$$\text{Ratio on applied tension ult:} \quad Rau_1 := \frac{SF_{\text{U}}_{\text{FS}} \cdot P_{\text{FS}} \cdot FF}{PAt}$$

$$\text{Ratio on total tension ult:} \quad Rau_2 := \frac{Pb_{\text{FS}}}{PAt}$$

$$\text{Margin of safety on total tension load ultimate:} \quad MS_{\text{FS3}} := \frac{PAt}{Pb_{\text{FS}}} - 1$$

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Margin of safety on thread shear using direct tension only

$$\text{MS_FS}_4 := \begin{cases} 10.0 & \text{if } P_{\text{FS}} = 0 \cdot \text{lbf} \\ \frac{P_{\text{pths}}}{SF_{\text{u_FS}} \cdot P_{\text{FS}} \cdot FF} - 1 & \text{otherwise} \end{cases}$$

Margin is based upon the total tension load

$$\text{MS_FS}_5 := \frac{P_{\text{pths}}}{P_{\text{b_FS}}} - 1$$

Margin of safety on applied shear load ultimate:

$$\text{MS_FS}_6 := \begin{cases} 10.0 & \text{if } V_{\text{FS}} = 0 \cdot \text{lbf} \\ \frac{V_{\text{Au}}}{(SF_{\text{u_FS}} \cdot |V_{\text{FS}}|) \cdot FF} - 1 & \text{otherwise} \end{cases}$$

Shear ratio ult.: $R_{\text{su}} := \frac{SF_{\text{u_FS}} \cdot |V_{\text{FS}}| \cdot FF}{V_{\text{Au}}}$

Margin of safety on applied moment ultimate:

$$\text{MS_FS}_7 := \begin{cases} 10.0 & \text{if } M_{\text{FS}} = 0 \cdot \text{in} \cdot \text{lbf} \\ \frac{MA_{\text{u}}}{SF_{\text{u_FS}} \cdot |M_{\text{FS}}| \cdot FF} - 1 & \text{otherwise} \end{cases}$$

Moment ratio: $R_{\text{bu}} := \frac{SF_{\text{u_FS}} \cdot |M_{\text{FS}}| \cdot FF}{MA_{\text{u}}}$

Guess K

$$K_{\text{ru}} := 1.0$$

Given

$$(K_{\text{ru}} \cdot R_{\text{su}})^3 + [K_{\text{ru}} \cdot (\max(R_{\text{au}}) + R_{\text{bu}})]^2 = 1 \quad K_{\text{ru}} := \text{Find}(K_{\text{ru}})$$

Margin of safety on combined loading ultimate:

$$\text{MS_FS}_8 := K_{\text{ru}} - 1$$

Summary of Margins for bolt: $\text{MS}_{\text{bolt_FS}} := \min(\text{MS_FS})$

$\text{Failure_Mode_FS} :=$	$"\text{Joint Separation}" \text{ if } \text{MS_FS}_1 = \min(\text{MS_FS})$ $"\text{Direct Tension Ultimate}" \text{ if } \text{MS_FS}_2 = \min(\text{MS_FS})$ $"\text{Total Tension Ultimate}" \text{ if } \text{MS_FS}_3 = \min(\text{MS_FS})$ $"\text{Direct Thread Shear Ultimate}" \text{ if } \text{MS_FS}_4 = \min(\text{MS_FS})$ $"\text{Total Thread Shear Ultimate}" \text{ if } \text{MS_FS}_5 = \min(\text{MS_FS})$ $"\text{Shear Ultimate}" \text{ if } \text{MS_FS}_6 = \min(\text{MS_FS})$ $"\text{Bending Ultimate}" \text{ if } \text{MS_FS}_7 = \min(\text{MS_FS})$ $"\text{Combined Shear Tension Bending Ultimate}" \text{ if } \text{MS_FS}_8 = \min(\text{MS_FS})$
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Summary of Margins for bolt:

Direct Tension Ultimate

$$MS_FS_2 = 1.788$$

Total Tension Ultimate

$$MS_FS_3 = 0.421$$

Shear Ultimate

$$MS_FS_6 = 4.565$$

Direct Thread shear Ultimate

$$MS_FS_4 = 2.651$$

Bending Ultimate

$$MS_FS_7 = 10$$

Total Thread shear Ultimate

$$MS_FS_5 = 0.861$$

Combined shear, tension
and bending ultimate

$$MS_FS_8 = 0.41$$

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ANNEX 2.

THE MODIFIED PROGRAM FOR MOS OF JOINT1 ALLOWABLE CHECK

The data come from ANNEX-1 Program output.

Loads

Applied tensile load $P := 5394.3 \text{ N}$

Applied shear load $V := 1639.6 \text{ N}$

Applied bending moment $M := 0.0 \text{ m} \cdot \text{N}$

Ultimate $SF_u := 2.0$ Yield $SF_y := 1.25$

Fitting factor $FF := 1.15$ $n := 0.5$ $\phi := 0.45\delta$ $\alpha := 0.97$

Max. preload $PLD_{max} := 15138.8 \text{ N}$

Min. preload $PLD_{min} := 5765.1 \text{ N}$

The allowables of CS5108C-4-6 captive bolt by F.I.T Inc.

Bolt ultimate tensile allowable $PAt := 590 \text{ lbf}$

Bolt yield tensile allowable $PAy := 0.75 \cdot PAt$ $PAy = 1.968 \times 10^4 \text{ N}$

Bolt ultimate shear allowable $VAu := 360 \text{ lbf}$

Total tensile load on bolt $Pb := PLD_{max} + n \cdot \phi \cdot (SF_u \cdot P \cdot FF)$

Total Yield tensile load on bolt $Pby := PLD_{max} + n \cdot \phi \cdot (SF_y \cdot P \cdot FF)$

Margin of safety on applied tension load ultimate: $MS_2 := \begin{cases} 10.0 & \text{if } P = 0 \cdot \text{lbf} \\ \frac{PAt \cdot \alpha}{(SF_u \cdot P) \cdot FF} - 1 & \text{otherwise} \end{cases}$

$$\text{Ratio on applied tension ult: } RAU_1 := \frac{SF_u \cdot P \cdot FF}{PAt \cdot \alpha}$$

Margin of safety on applied tension load Yield: $MS_3 := \begin{cases} 10.0 & \text{if } P = 0 \cdot \text{lbf} \\ \frac{PAy \cdot \alpha}{(SF_y \cdot P) \cdot FF} - 1 & \text{otherwise} \end{cases}$

$$\text{Ratio on applied tension yield: } Ray_1 := \frac{SF_y \cdot P \cdot FF}{PAy \cdot \alpha}$$

Margin of safety on total tension load ultimate: $MS_4 := \frac{PAt \cdot \alpha}{Pb} - 1$

$$\text{Ratio on total tension ult: } RAU_2 := \frac{Pb}{PAt \cdot \alpha}$$

Margin of safety on total tension load (Yield):

$$\text{MS}_5 := \frac{\text{PAy} \cdot \alpha}{\text{Pby}} - 1$$

Ratio on total tension (Yield)

$$\text{Ray}_2 := \frac{\text{Pby}}{\text{PAy} \cdot \alpha}$$

Ratio on preload (Yield):

$$\text{Ray}_{\text{3}} := \frac{\text{PLDmax}}{\text{PAy} \cdot \alpha}$$

Margin of safety on applied shear load
ultimate:

$$\text{MS}_8 := \begin{cases} 10.0 & \text{if } V = 0\text{-lbf} \\ \frac{V A u \cdot \alpha}{(S F u \cdot |V|) \cdot F F} - 1 & \text{otherwise} \end{cases}$$

$$\text{Shear ratio ult.: } R_{su} := \frac{SF_u \cdot |V| \cdot FF}{VA_u \cdot \alpha}$$

Guess K

Kru := 1.0

Given

$$(Kru \cdot Rsu)^3 + [Kru \cdot (\max(RAU))]^2 = 1 \quad Kru := \text{Find}(Kru)$$

Margin of safety on combined loading ultimate:

$\text{MS}_{10} := \text{Kru} - 1$

Summary of MoS based on FIT allowables

Direct Tension Ultimate

$$MS_2 = 1.052$$

Direct Tension Yield

$$\text{MS}_2 = 1.462$$

Total Tension Ultimate

MS_c = 0.416

Total Tension Yield

MS = 0.129

Shear Ultimate

MS 3.119

Combined shear, tension and bending ultimate

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ANNEX 3.

THE PROGRAM FOR BEARING, TENSION AND SHEAR OUT VERIFICATION

Bearing, tension and shear out verification for lug near JOINT 1

FACTORS of SAFETY Ultimate: $FS_u := 2.0$ Yield: $FS_y := 1.25$

Nominal diameter: $D := 9.9 \cdot mm$

Plate Thickness [mm] : $Thk := 6.3mm$ $Thk = 6.3 \times 10^{-3} m$

Temperature derating factor $\alpha_c := 0.97$

The material properties of lug

Tensile allowable, ultimate: $F_{tu} := 468.9 \cdot 10^6 \cdot Pa$ Tensile allowable, yield: $F_{ty} := 393 \times 10^6 Pa$

$F_{bru}(plate) [Pa] := F_{bru} := 710.2 \cdot 10^6 \cdot Pa$ $F_{bry}(plate) [Pa] := F_{bry} := 558.5 \cdot 10^6 \cdot Pa$

$FS_u(plate) [Pa] := FS_u := 262E6 \cdot Pa$ $FS_y(plate) [Pa] := FS_y := 219E6 Pa$

Forces at the Bolts:

Bolt tensile force (N) : $F_{ten} := 5394.3 \cdot newton$

Bolt shear force (N) : $F_{shear} := 1639.6 \cdot newton$

Calculate Margins of safety for Bearing:

Limit Shear Force [N] : $Shear := F_{shear}$

Limit Stress [Pa] : $Sh := \frac{Shear}{Thk \cdot D}$ $Sh = 2.629 \times 10^7 Pa$

$MoS_{bry} :$ $MoS_{bry} := \left(\frac{F_{bry} \cdot \alpha_c}{Sh \cdot FS_y} \right) - 1$ $MoS_{bry} = 15.486$

$MoS_{bru} :$ $MoS_{bru} := \left(\frac{F_{bru} \cdot \alpha_c}{Sh \cdot FS_u} \right) - 1$ $MoS_{bru} = 12.103$

Calculate Margins of safety for tension failure:

Distance hole-end plate [mm] : $Dis := 3.2mm$ $Dis = 3.2 \times 10^{-3} m$

Limit Shear Force [N] : $Shear := F_{shear}$

Limit Stress [Pa] : $Sh := \frac{Shear}{Thk \cdot Dis \cdot 2}$ $Sh = 4.066 \times 10^7 Pa$

$MoS_{lug\ ty} :$ $MoS_{lug\ ty} := \left(\frac{F_{ty} \cdot \alpha_c}{Sh \cdot FS_y} \right) - 1$ $MoS_{lug\ ty} = 6.5$

$MoS_{lug\ tu} :$ $MoS_{lug\ tu} := \left(\frac{F_{tu} \cdot \alpha_c}{Sh \cdot FS_u} \right) - 1$ $MoS_{lug\ tu} = 4.592$

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Calculate Margins of safety for shear out failure:

$$\text{MoS lug sy :} \quad \text{MoSlugsy} := \left(\frac{F_{sy} \cdot \alpha_c}{Sh \cdot FS_y} \right) - 1 \quad \text{MoSlugsy} = 3.179$$

$$\text{MoS lug su :} \quad \text{MoSlugsu} := \left(\frac{F_{su} \cdot \alpha_c}{Sh \cdot FS_u} \right) - 1 \quad \text{MoSlugsu} = 2.125$$

For bearing, tension and shear out verification the lug formulas from Bruhn "Analysis and design of flight vehicle structures" are used.